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DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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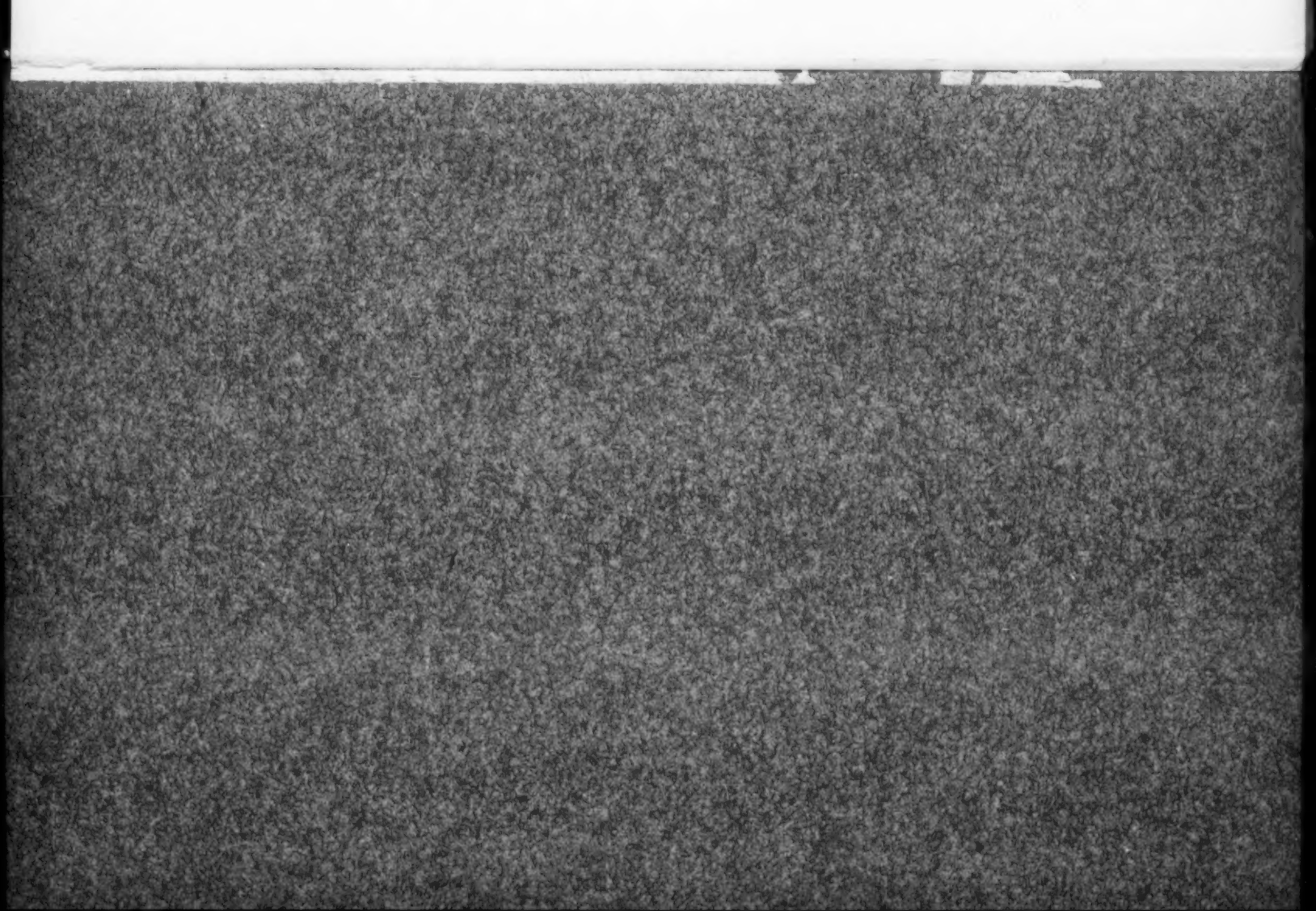

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VOL. I. MARCH-APRIL, 1907. No. 2.

In Memoriam	*T. E. Heath*	81
Agnes Mary Clerke	*Elsie A. Dent*	81
Time Service at the Dominion Observatory	*R. M. Stewart*	85
Adapting a Universal Spectroscope for Radial Velocity Determinations	*J. S. Plaskett*	104
Magnetic Disturbances Recorded at the Agincourt Observatory	*R. F. Stupart*	122
Thoughts on Meteorology and Terrestrial Magnetism	*Andrew Elvins*	125
Meetings of the Society		
At Toronto	*E. A. D.*	127
At Ottawa	*J. S. P.*	129
Notes from the Dominion Observatory		133
Brief Astronomical Reviews		138
Errata in *Handbook for 1907*		139
Astronomical News		140
Summary of Weather of Canada for February and March		141

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PLATE III.

Agnes M. Clerke

Journal of the Royal Astronomical Society of Canada, 1907.

THE JOURNAL

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OF CANADA

VOL. I. MARCH-APRIL, 1907. No. 2.

IN MEMORIAM.

Hers was the part to glean the scattered grains
  Of Truth, which reach us from the starry field;
  To weigh results which calculations yield,
See where they tend, and gather up the gains
Of many a night-long watch. She remains
  The mistress of a style whose greatness sealed
  It to sublimest science, which revealed
Deep study, and far reaching thought contains.

And she who, judging the cosmogonies,
  Marked what they lacked, dimly perceived how
    A Power outside of Nature guideth all
By ordered paths—a Power which vivifies
  And upwards leads. She has gone from us now,
    And from her eyes earth's darkening glasses fall.

T. E. HEATH, in *Knowledge*.

AGNES MARY CLERKE.

BY ELSIE A. DENT.

IN the death of Agnes Mary Clerke, which took place on the 20th of January last, the scientific world loses one of its most useful and distinguished members, and this Society one of its most highly valued Corresponding Fellows. Death was due to pneumonia following an attack of influenza. The funeral services took place at the Church of the Servites, London, where Requiem Mass was celebrated on the 23rd of January.

Miss Clerke was one of the four eminent women upon whom, by virtue of scientific attainments, Fellowship in the Royal Astronomical Society has been conferred. The others were Miss Caroline Herschel, Mrs. Somerville and Lady Huggins.

As a clear and forceful writer on astronomical subjects Miss Clerke was almost unrivalled. Her knowledge was deep and thorough; her outlook was broad, and her attitude as a student of the heavens fearless but reverent. Her original investigations covered many subjects, such as studies of star colours, star distribution, the classification of stellar spectra, variable stars, etc., but her great skill in compiling the results of the work of others, and her keen insight in comparing and discriminating as to the bearing and value of different classes of evidence, almost overshadowed her own investigations. The value of her books is enhanced by their charming literary style, fluent yet dignified language, and general grace of expression. They are notable as works of literature as well as of science.

Agnes Mary Clerke, daughter of John William Clerke, was born in the County of Cork, Ireland, on the 10th of February, 1842. Though her astronomical reading began when she was a child of eleven years, her education was not designed to fit her for scientific work. In reply to a question of the writer on the subject she said:

"The truth is bare and bold enough in sound, that in the scientific sense I had no education, but just picked up what came my way. I had a childish passion for natural knowledge and read the books accessible to me in my father's library, taught myself with the minimum of assistance some elementary mathematics, and that was all. I was also very delicate growing up and never went to school . . . . . but I had admirable instruction from private professors in languages and music. I had from time to time tried writing stories and poetry, with indifferent success; but in Italy I undertook more serious work and contributed on various topics to the *Edinburgh Review* from 1877. An article on 'The Chemistry of the Stars' made a turning-point. The studies for it revived my astronomical tendencies; Messrs. Black accepted my proposal to write for them a history of recent astronomy, and so I went on."

The publication of "A Popular History of Astronomy in the Nineteenth Century," upon which she spent the work of

four years, brought her at once to the attention of the scientific world. The book was at once recognized as a most important contribution to astronomical literature. It reached its fourth edition in 1902, and has been translated into German.

"The System of the Stars," published in 1888, contains the result of several months' work at the Cape Observatory, studying the southern heavens under the guidance of Sir David Gill. The second edition, published in 1905, is largely re-written, in view of the progress which had been made in astronomical research since its first appearance. The same remark may be made of the "History," which was not permitted to become out of date.

"Problems in Astrophysics," published in 1903, deals essentially with twentieth century astronomical science. It embodies not only a history of what has been accomplished in astrophysical research, but it suggests the directions of possible and probable advance and development, stimulating the worker to further investigation. The Fellowship in the Royal Astronomical Society which was conferred upon the appearance of this book was no doubt intended as a public recognition of the value of her services to astronomy.

"The Herschels and Modern Astronomy," published in 1895, is a short history of the celebrated family and its contributions to astronomical science.

Shorter works are "Familiar Studies in Homer," published in 1892; two sections of "Astronomy" in the *Concise Knowledge Series*; the "Hodgkins Essay" on Temperature Research at the Royal Institution, 1901; about one hundred sketches of the lives of scientific men for the *Dictionary of National Biography*, and many of the articles in the *Encyclopaedia Britannica* upon the life and work of such men as Galileo, Kepler, Laplace, etc.

The last work, published a year ago, was "Modern Cosmogonies." It is a review of the theories of the universe which have been advanced from time to time, with a discussion as to their merits and defects.

The London *Times*, commenting on the death of Miss Clerke, (Feb. 22nd, 1907), said : "No worker in the vast field of modern sidereal astronomy opened by the genius of Herschel and greatly advanced by the application of the spectroscope to the chemical and physical problems of the universe lacked due recognition by Miss Clerke, who performed as it seemed no other writer could have done the work of collation and interpretation of this enormous mass of new material, ever pointing the way to new fields of investigation, often by one pregnant suggestion sweeping aside a whole sheaf of tentative conjectures, and indicating, if not the true line—for in many cases the truth is yet to seek—at least a plausible and scientific line well worth pursuing. She will be missed at the meetings of the Royal Astronomical Society, at which she was a constant visitor . . . . . where her clear judgment was at times called upon to determine the value of some new suggestion in the domain of celestial physics."

The death occurred some months ago of Miss Ellen M. Clerke, sister of Mary Agnes Clerke. While her literary and scientific work did not reach the high level attained by that of her gifted sister, she was well known as a writer of magazine articles on various subjects, astronomical and otherwise.

THE TIME SERVICE AT THE DOMINION OBSERVATORY.

By R. M. Stewart.

FOR many years there has been in commercial life a growing recognition of the fact that wherever large numbers of people have dealings with one another, and particularly in schools, factories, or extended offices, where many men are employed, a uniform system of time is not merely a convenience, but a necessity. It was a realization of this need in connection with the Government service at Ottawa that prompted the experimental installation some five years ago of a small system of electrically connected clocks in the Department of Interior. At that time they were controlled from the old offices of the Astronomical Branch on Wellington Street. On the completion of the Observatory the modified form of the system which had been evolved was extended throughout the Parliament Building and the three Departmental Buildings adjacent, and the centre of distribution was of course removed to the Observatory. In addition to this mean time system, there is required for the purposes of the Time Service itself, and for use in making observations, a system of sidereal clocks in the Observatory. These two systems, with the auxiliary electrical appliances required, and with the addition of a transit instrument for time observations, comprise the apparatus used in connection with the Time Service.

Each of these clock systems consists of a primary clock situated in the Clock Room, and any required number of secondary clocks and dials electrically controlled by the primary. There are at present in use five secondary mean time "master clocks" synchronized in the manner described below by the mean time primary; one of these is in the Time Room at the Observatory, and one in each of the Government Buildings

referred to above; each master clock in its turn operates a number of electrically driven dials in the building where it is situated. In this way every clock in the system shows the same uniform time as the primary clock at the Observatory, while the division into units operated by separate master clocks reduces as far as possible the danger of derangement by accidents to wires connecting different buildings.

For the primary clocks, and more especially for the Sidereal Standard, to which all time is referred, it is a prime requisite to be protected as fully as possible from all outside influences such as vibration and changes of temperature. Accordingly they are mounted in a specially prepared Clock Room which is situated nearly in the centre of the Observatory basement, so that fluctuations in the outside temperature may be as little felt as possible; with the same end in view, it is separated from the rest of the basement by double doors which are kept always closed. For all ordinary purposes this would probably suffice; but, not so much from a consideration of the requirements of the Time Service in itself, as because in refined meridian observations the most extreme accuracy of rate attainable by any means is demanded of the Sidereal Standard, it is desirable to keep the temperature of the latter as near an absolutely constant value as possible. The most convenient way of attaining this end is by using an electric heater to keep the temperature at a somewhat higher value than is ever reached in the remainder of the building; the particular temperature fixed on is maintained by an automatic relay arrangement for supplying current to the heater whenever necessary. In order that the temperature may be as nearly uniform in all parts of the room as possible, an electric fan is arranged to play continually over the surface of the heater, so as to dissipate the heat and keep the air in constant circulation throughout the whole room. The controlling mechanism at first was a special form of minimum thermometer which closed an electric circuit when the temperature fell. This proving unsatisfactory, a thermostat was made consisting of two strips, one of hard rubber, the other of brass,

fastened firmly together and having one end of the compound bar attached to a base-plate. Changes in the hard rubber, due to atmospheric moisture, rendered this arrangement inconstant in its action, and it was discarded. Last December a Callendar Recording Thermometer, which both controls and records the temperature, was installed. This instrument is essentially a self-balancing Wheatstone Bridge. In one arm is inserted the platinum resistance thermometer, while attached to the moving coil of the galvanometer is a long light boom which completes one of two electric circuits according as the coil is deflected in one direction or the other. These circuits control two clocks which are connected to a sliding carriage, and attached to this is a recording pen which follows the temperature with great nicety. The thermometer is of the most recent open-wound type, and being of fine wire it follows quickly the variations of the temperature of the surrounding air. The thermometer is the only part of the instrument in the Clock Room, the rest of it being in the Time Room. The Recorder is an almost ideal instrument for regulating temperature.

We are thus enabled to keep any one point in the Clock Room (that corresponding to the position of the platinum thermometer) at a very constant temperature. The other parts of the room are kept very nearly at the same point by the constant air circulation induced by the electric fan, and before the installation of the Recorder it was thought that this might be a sufficient precaution. Since that time, however, it has become evident that there are somewhat irregular variations at a distance from the thermometer, which, though very slight, are sufficient to disturb that ideal uniformity at which we must aim. Consequently an outside heat-proof case, built with refrigerator walls, has been made for the Sidereal Standard, which is the only clock to which it is worth while to apply this last refinement. A partition is so arranged in the case that a small fan will draw a constant current of air through a heater and around the clock; the heater will be controlled by the Callendar apparatus, while a rougher means of control will be used for the room at large.

At the time of writing, this case is in position, but the arrangements for its separate heating have not yet been installed.

Just as important as temperature regulation is the protection of an accurate clock from all mechanical disturbances and vibrations, as well as from the influence of other clocks. In regard to the latter, it is an easily demonstrable fact that if two pendulums of equal periods be hung in parallel planes from the same support, however firm it may apparently be, the oscillations of one of them will have sufficient influence to start the other swinging in a comparatively short time. In the Clock Room therefore, there are four cement piers, each built on a separate foundation entirely independent of the building, and each surrounded up to the level of the floor by a brick wall; embedded in each is a vertical marble slab, upon which the clock is securely bolted. They are disposed in pairs, one pair at each end of the room; and the two units of each pair are set at right angles, to obviate the mutual influence of their pendulums; as an additional safeguard, one of the clocks of each pair is a sidereal and the other a mean time, as the inequality of their rates will still further lessen any influence they might have upon each other. Two of these four clocks are of course the Sidereal Standard and the Mean Time Primary. The other two are reserves, to be used in place of the principal ones at any time when the latter may be out of commission through accident or for repairs or for any other reason.

The Sidereal Standard was made by Riefler of Germany. His clocks are so well known throughout the world that a detailed description of one of them seems almost superfluous; however, there are some points which may be of interest here. One of the unique features, and the one which is on the whole perhaps the most beneficial, is that the whole clock is enclosed in an air-tight glass cylinder which is partially exhausted. One of the most fruitful sources of irregular error in a clock is the fluctuation of rate due to changes in atmospheric pressure. The buoyancy of the air in which a pendulum swings has the effect of diminishing its effective weight by the weight of air displaced;

a change in the density of the air will mean a change in the effective weight of the pendulum, which is equivalent in effect to a change in the force of gravity. Hence a pendulum which keeps true time at a particular pressure will gain if the pressure be decreased, and vice versa ; in addition, there may be a secondary effect due to variations in the friction of the air on the pendulum. At all events, a clock running in the open air will lose from ¼ sec. to ½ sec. per day for a rise of one inch in barometric pressure ; and if at all avoidable, such a variation is not to be tolerated in an astronomical clock. One device used to compensate this error is a mercury barometer of the proper cross-section attached to the pendulum rod ; in this way the rise of the mercury in the barometer tube may be made to raise the centre of gravity of the pendulum just about enough to counteract the effect of the increased density of the air. In the Greenwich Sidereal Clock a magnetic device was used for some years, by which a permanent magnet fixed beneath the pendulum was raised or lowered by gearing connected to a barometer, so as to supplement the force of gravity. But all such arrangements must necessarily be more or less approximate ; the simplest and most effective way is, as Riefler does, to seal the whole clock in an air-tight case. The only difficulty to be contended with is the obtaining of a perfectly air-tight joint ; and that this is possible is amply demonstrated by the fact that during the last eight months our Riefler clock has not leaked by so much as a millimetre of mercury. Previous to that time there had been a slight leak which proved troublesome ; but it was located in the bushing which carried the leads for the winding and recording circuits, and remedied by the insertion of a new bushing.

The pendulum rod is of nickel-steel, of composition 35·7 per cent. nickel and 64·3 per cent. steel, an alloy which, when combined in these proportions, gives a minimum coefficient of expansion, being only about one twelfth that of steel. The temperature compensation is a metallic one, and consists of two short tubes surmounting one another, resting on the regulating nut at the bottom of the pendulum rod. The lower tube is of

brass, the upper one of steel; from the top of this the pendulum bob is supported exactly at its centre. The lengths of the two tubes are adjusted by experiment so as to give as perfect a compensation as possible.

One of the most unique features of the Riefler clocks is the escapement, like which, so far as I am aware, there is no other in existence. The pendulum, as in all astronomical clocks, is hung from its support by a thin flexible steel spring, but in this case the support, instead of as usual being a fixed one, is a carriage mounted on **V's**, so as to allow motion in the same plane as that of the pendulum. The escapement, though at first sight apparently of the ordinary anchor type, is nevertheless really a detached one; that is, the pendulum is free from all influence of the clock train except at the moment of receiving the impulse. The anchor, instead of engaging the pendulum, as is the usual arrangement, is fixed rigidly on the carriage mentioned above, and the pallets are held without motion by a tooth of a detent-wheel on the same arbor as the escape wheel; in this way all friction between the pendulum and the escape wheel is avoided. When the pendulum reaches the proper position the pallets slip off the tooth of the detent-wheel, and at the same instant receive the impulse from the escape wheel, being locked again immediately. In this way the impulse is given, not to the pendulum directly, but to the carriage from which it hangs, and transmitted to it through the suspension spring. When the pallets are locked the carriage is of course at rest, and in transmitting the impulse it simply makes a slight swing in the proper direction, returning immediately to its original position. Another advantage of this escapement is, that whatever the variation of force of the clock-train, the impulse given to the pendulum is always the same, since the amount of displacement of the carriage is determined solely by the size of the teeth of the escape wheel. In this way it practically combines in itself all the advantages of a detached and of a gravity escapement.

The hermetic sealing of the clock makes it necessary to

have an electric self-winding arrangement. The clock-weight consists merely of a small lever weighing ten grams, which is attached by a going-ratchet to a wheel which engages the pinion of the escape wheel When the lever has dropped to a certain point it closes an electric circuit which raises it again to its highest position ; this action recurs every 20 or 30 seconds. .

There is also an electric contact for recording on chronographs or synchronizing secondary clocks. It is of the "intermittent" type—that is, the circuit controlled by it remains open and closed during alternate seconds. On the arbor of the escape wheel there is fixed a contact wheel *c* (Fig. 1) having 29 teeth and one blank space ; the teeth engage the jewel *p* at the end of

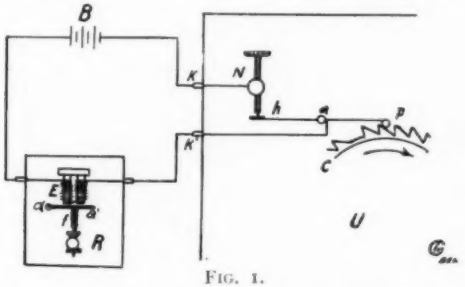


FIG. 1.

the light lever pivoted at *a*, which carries the contact piece *h* on the other end ; as the wheel revolves, the circuit between *h* and the adjustable contact screw at *N* is closed and opened at alternate beats of the clock ; the blank space serves for the identification of the even minute.

This intermittent type of circuit is the most useful one for synchronizing secondary clocks, but is unsuited for use with a chronograph for recording observations ; for this purpose a closed circuit is required, with a short, sharp break at every alternate second. Accordingly an arrangement was devised for transforming the former into the latter, so that both types of circuit could be obtained from the single contact. Fig. 2 illustrates the apparatus used for this purpose, comprising three relays connected in the manner shown. The relay *A* is the one

controlled by the intermittent circuit; *B* is a differentially wound, neutrally adjusted polar relay, and *C* the relay which operates the transformed circuit. When the armature *a* of the relay *A* is held against the back contacts *b* and *c*, as shown in the figure, the circuit from the battery *E* holds the relay *C* closed, while it also so operates the relay *B* that the circuit through its points is open. When, on the opening of the primary circuit, the armature *a* leaves *b*, the circuit through *C* is opened; as soon, however, as *a* touches the front contact *f*, a circuit through *B* is completed which draws its armature to the right, again closing the circuit through *C*, which has thus been open only momentarily. When, a second later, *a* is again drawn down by the magnets, the armature of *B* returns to the left, *after*

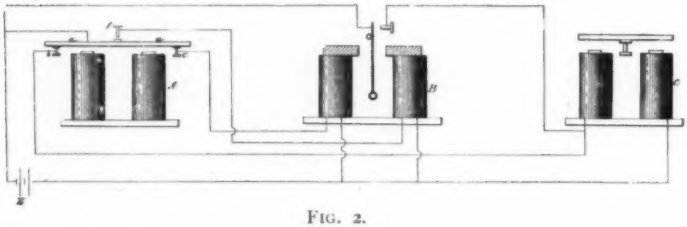


FIG. 2.

the circuit of *C* has been closed through *a b*. Consequently, the action of *C* consists of a short, sharp break every alternate second, as with an ordinary break-circuit contact. This device has been in use now for over a year and has given perfect satisfaction. The transformed circuit is used only for recording, the primary intermittent circuit performing the synchronizing functions of the clock, which are described below.

The synchronizing circuits operated by the Riefler are two in number; one controls a secondary clock in the Time Room, the other is applied to the equatorial telescope to equalize the rate of its driving clock. The function of the secondary clock in the Time Room, besides furnishing sidereal time there for purposes of computation, is to act as a master clock for running

electric seconds-dials in the Transit Room, the Meridian Circle Room, and the Equatorial Room. At the bottom of the clock-case, and to one side, just below the pendulum, there is a fixed vertical electro-magnet through which the intermittent synchronizing current flows; at the lower end of the pendulum-rod, below the bob, is a horizontal brass arm with an iron armature attached, which is attracted by the electro-magnet while the current flows; by means of the impulse thus administered every alternate second the pendulum is kept swinging in synchronism with that of the controlling clock.

In the case of the driving clock of the equatorial the same method of synchronization could not be followed, for the reason that the pendulum is of the conical type required for giving a continuous motion to the driving gear. To meet this difficulty, a plan of synchronization was designed in principle by the writer, and put in practical shape and installed by Mr. Plaskett, who has charge of the telescope. Fig. 3 shows the driving clock with the attachment complete. *A* is a pinion on the axis of the conical pendulum, driving the wheel *B*, which is mounted on a vertical shaft; the gearing is so arranged that *B* turns once in two seconds. *C* is an armature of soft iron in the form of a rim fixed to the wheel *B*, while *D* is a balancing rim of brass. A strong electro-magnet *E* is set horizontally with its poles just clearing the rims *C* and *D*; a fairly strong current controlled by the relay *F* passes through the magnet; the relay is operated by the synchronizing circuit. The armature *C* is attracted by the electro-magnet every alternate second, and the wheel *B* thus kept in step with the Sidereal Standard; the circuit is opened by the switch *G* when the telescope is not in use. Mr. Plaskett informs me that the synchronization is a considerable convenience in observing, as the telescope will now follow a star accurately except for the variations arising from change of altitude.

The clock error of the Riefler, as is usual with sidereal clocks, is allowed to accumulate, and is determined every few days by astronomical observations. The observations at present

are taken with a transit instrument mounted in the meridian, but the method of making them, as in many other observatories, is in a somewhat transitional stage. Up to the present winter the writer has always used the ordinary key-and-chronograph method, but the so-called "personal error" inevitable in this method is practically eliminated by using the travelling-wire

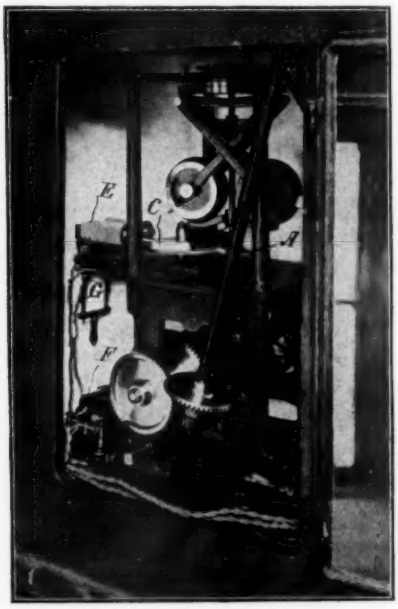


FIG. 3.

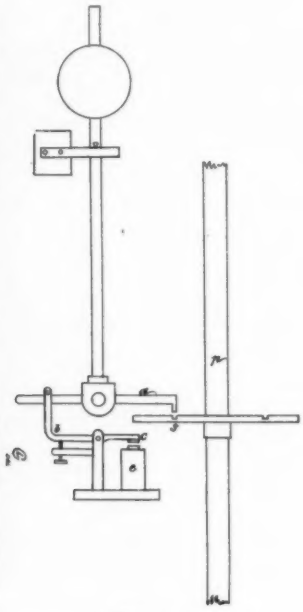


FIG. 4.

micrometer, which will in time completely supersede the key. A complete time determination, in which ten or twelve stars are observed, if well made, will give an apparent probable error (as determined by the concordance of the separate observations) seldom much exceeding one hundredth of a second; but comparison of different sets of observations, however, goes to show that the results cannot be relied upon as closely as this; from consider-

able data which have been accumulated, the liability to error would appear on an average to be about four one-hundredths of a second. An investigation is at the date of writing in progress to discover the cause of this and if possible devise a remedy.

The Mean Time Primary is also a Riefler clock, though of an inferior type to the Sidereal. It has a nickel-steel pendulum and an ordinary dead escapement. The electric contact for controlling the synchronizing circuit is identical with the one shown in Fig. 1. A mean time clock is of course required always to show the true time; hence an arrangement becomes necessary for correcting small outstanding errors from day to day. In this case it consists of two small auxiliary pendulums mounted one on each side of the main pendulum; the method of controlling one of these is shown in Fig. 4. The one on the left has its centre of gravity slightly below its point of suspension, that on the right slightly above. It follows that if the first of these is connected to the main pendulum it will accelerate the clock, while the second will retard it. In using this method of correction elsewhere it has always been necessary to make connection between the pendulums by hand, but in this case it was desired to perform the whole operation without entering the Clock Room. Accordingly an electrical operating device was designed by the writer, and was made a part of the specifications when ordering the clock. The electro-magnet *e* (Fig. 4) is traversed by a circuit which runs to the switch-board in the Time Room; when the circuit is open, as is normally the case, the arm *a* is held clear of the shelf on the main pendulum-rod *p* by the arm *b* connected to the armature *c*; when the circuit is closed the armature is attracted, the arm *a* is released and drops into the slot *s*, thus throwing the auxiliary pendulum into connection with the main one; when the clock has been corrected to the required extent the circuit is opened and the arm *a* again lifted. The arrangement for the other auxiliary pendulum is similar. The rate of correction can be adjusted by moving the bobs of the auxiliary pendulums on their rods. That used is about six seconds per hour, so that a correction of a tenth of a

second either way can be made by simply throwing the switch in the Time Room in the required direction for the space of a minute. The clock is compared by chronograph with the Sidereal Standard every morning, and the proper correction made, if any is necessary.

As stated above, the Mean Time Primary synchronizes five secondary master-clocks, of which one, which is used also as a signal clock, is mounted in the Time Room. The synchronization is effected in the same way as that of the sidereal clock described above. In the case of the experimental system before referred to, which was installed in the Department of the Interior some years ago, the synchronization depended on a different principle. In place of the vertical electro-magnet there was a horizontal solenoid, through which passed one end of a permanent bar magnet attached horizontally to the lower end of the pendulum rod; the other end of the magnet passed through a copper cylinder which served to damp the oscillations of the pendulum and keep it under control. This system, however, was found to be open to several objections, the most serious of which was that if from any cause (as was sometimes liable to happen when wires from one building to another were used) the synchronization current failed to flow, even for a few minutes, the synchronized clock must necessarily stop. Hence the present system, due to Riefler, was adopted, and has given complete satisfaction. It may be remarked that the controlled pendulum lags in every case about four-tenths of a second behind the controlling one; any error in indicated time is of course obviated by keeping the controlling clock that amount fast on true time.

The signal clock operates several electric contacts, used for controlling different circuits. The first one works a number of electric dials distributed throughout the Observatory. The dials have no clock movement of their own, but contain simply an electro-magnet, with the necessary mechanism for transforming the electro-magnetic impulses into the movement of the hands. The contact controlling them is closed from the 59th to

the 60th second of every minute, so that the hands do not move gradually, but jump the space of one minute at a time, advancing always at the 60th second as indicated by the master clock. In addition, the Tower Clock of the Observatory is operated by the same circuit, but in a different way; on account of its size, and the resistance encountered by the hands from the wind and in the winter from snow and sleet, the same method would be impracticable in its case. The hands are operated by a small motor which is cut in every minute by an electro-magnet connected with the minute-dial circuit; as soon as it has advanced the hands the space of one minute, it automatically cuts itself out, the time required for the movement of the hands being somewhat less than a second. The motor and auxiliary mechanism are situated just back of the dial, in an alcove off the Equatorial Room. The dial is of sectional ground glass, of five feet diameter, and is equipped with lights for illumination. This is effected by a white back-board illuminated by eight 16 c.p. lamps arranged with reflectors around its edge between it and the dial.

Another circuit, which flows for two seconds every minute, is employed for registering the time on the record sheets of the seismograph. The seismograph record is made by a beam of light on a revolving drum carrying a sheet of sensitive paper; the circuit operates a shutter, which when energized, shuts off the light; the record thus consists of a line with breaks corresponding to successive minutes; the break corresponding to the even hour is omitted by means of an auxiliary hourly circuit, for convenience in reading the time from the record.

Since December 1, 1905, the time ball on Parliament Hill, which gives the signal for the firing of the noon-day gun, has been dropped by the signal clock. For this purpose two separate circuits are combined; one is closed for the first second of every minute, the other from about half a minute before each hour to a few seconds after; the combination of the two gives an hourly signal, so that whenever the time-ball is raised it will

be dropped automatically by the clock exactly at the even hour next following.

Time signals are sent out every day at noon to the Great North-Western Telegraph Co., which distributes them over its lines. The time signal relay beats seconds, omitting the twenty-ninth second, and the last five seconds, of every minute; at the end of every fifth minute the last ten seconds are omitted, and at every even hour there is a single beat lasting one second, after which the line remains open for five or ten seconds. This circuit is switched on the telegraph line every day at 11.55 a.m., and turned off a few seconds after noon, the operation being performed automatically by a programme clock connected to and operated by the signal clock. The programme clock is of the minute-dial type, with a drum carrying a graduated paper ribbon which can be perforated at points corresponding to any required hour and minute; when the perforation reaches a certain point as it is carried around by the drum, it allows a spring to make a contact through the perforation and close an electric circuit. There is also a wheel revolving once a week, by which the circuit may be cut out automatically if so desired, on any required day or days.

A simple apparatus has also been arranged by which the time signals can be sent out by telephone at any time. Beneath the writer's desk there is fixed a transmitter connected in multiple with the desk telephone, and in front of this is mounted a sounder which can be switched on the signal circuit at will. When carrying on a conversation over the telephone, the turning of a switch under the desk throws the sounder into operation, and the signals become distinctly audible at the other end of the line.

The battery power required for the Time Service is obtained from 26 storage cells situated in the Battery Room in the basement, which are charged once or twice a week by the generator in the work-shop; the circuits are controlled from the switchboard in the Time Room. On the lower part of the switchboard is fixed a relay cupboard containing two shelves with

glass doors; in it are relays operated by the different clocks, which are used for controlling and subdividing the separate circuits as required. Just above the relay cupboard is a row of jacks through which the different circuits pass; on pushing a plug connected with the ammeter into any one of these, the ammeter is cut in without breaking the circuit.

Running from the Observatory to the city there are four insulated wires used by the Time Service, in addition to two bare telegraph wires. Of these one pair runs to the time ball on Parliament Hill; the other pair divides into several branches carrying the synchronization current for the master clocks in the Government Buildings. In each building there is a switch-room containing the master clock, a switch-board and relay-cupboard, a battery of storage cells, and a small motor-generator set for charging the battery. One of the master clocks is a duplicate of the signal clock at the Observatory, with the omission of several of the electric contacts; the others, however, were made by Riefler. The local synchronization current is worked from a relay driven by the main synchronization line from the Observatory. The battery consists of nine storage cells, giving a potential of about 18 volts; these are charged weekly. The motor-generator set is a Holzer & Cabot machine of 85 watts capacity. The motor is of the induction type, with a self-starting device, and runs on the ordinary alternating electric light circuit; it is coupled directly to a compound-wound generator giving 2·8 amperes at 30 volts. The charging circuit, which runs through a regulating rheostat on the switch-board, is usually turned on in the evening and off the next morning. In place of the ordinary no-load cut-out in the charging circuit, which, in case of a stoppage of the motor for even a few seconds due to failure of the electric light circuit, would cause the generator to run idle till morning, a special automatic low resistance relay is used. This consists, as shown in Fig. 5, of a pair of vertical coils and an armature with a horizontal arm attached. In the unexcited state of the relay this arm makes contact with the spring *s*, completing the generator circuit

through the coils of the relay and a suitable resistance *T*. When the generator starts, as soon as the voltage becomes high enough to attract the armature, the arm *a* is drawn down into the mercury cup *m*, closing the lower contact just as it breaks the upper one, and throwing the battery into circuit through the rheostat *R*.

The minute dials are divided into circuits of ten, which branch off wherever convenient from a pair of mains running to the switch-board; one of the dials is located in the switch-room for convenience in checking the coincidence of the system with

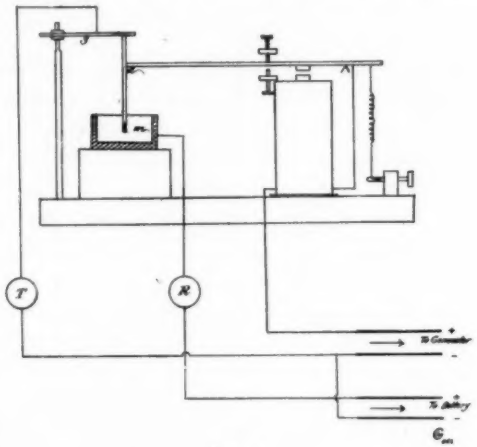


FIG. 5.

the master-clock. The dial circuit passes through the points of a relay controlled by the minute-contact on the master-clock, and also through the coils of a relay which serves to open the corresponding branch of the main synchronization line, so as to furnish a signal every minute at the Observatory. Provision is made, in case of necessity, for working the minute-dial relay in any one building from any other, using the synchronization wires for the purpose. Thus in case of accident to any one of the master clocks, or during repairs, the dials dependent on it could still provisionally be kept going.

As stated above, the dial circuit in each building is made to report itself every minute to the Observatory by opening the corresponding branch of the synchronization line ; a circuit has been so arranged at the Observatory that these signals may operate a check-dial there. A diagram of the connections employed for this purpose is shown in Fig. 6. The relay *A* is traversed by the main synchronization current ; when the synchronization line is closed the circuit through its points is open, and vice versa. *B* is a differentially wound, neutrally adjusted polar relay ; through one pair of coils the main synchronization line passes in such a direction as to close the circuit through the points ; through the other pair of coils, however, there flows in the opposite direction a stronger current, except

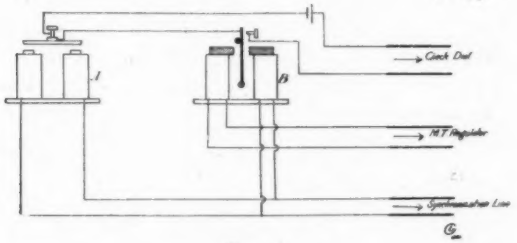


FIG. 6.

from the 58th to the 60th second of every minute ; this circuit is operated by one of the contacts in the signal clock. The circuit operating the check-dial passes in series through the points of these two relays. Evidently it will be held open at *B* up till the 58th second, and after this, since the relay is neutrally adjusted, it will remain open till closed by the flowing of the synchronization current ; this will next occur at the 59th second by the primary, which, it will be remembered, corresponds to about 58½ seconds by the synchronized clocks, due to the lag of the latter. The circuit through *B*, then, is closed for the last 1½ seconds of every minute, provided a current flows through the synchronization line just previous to the 59th second. At the 59th second, each of the branches of the synchronization line is

opened by the corresponding dial-circuit, and, provided there is no short circuit on the main synchronization line, the circuit through the points of *A* is thereby closed, and the check-dial is advanced one minute. In this way the check-dial will keep true time only so long as there is no short-circuit or break in the synchronization line, and so long as each of the dial-circuits operates properly. A failure of any one of these conditions makes it lose time, and give warning to the official in charge.

We have thus a system in which the dials in the different offices are operated by a central clock in each building. These central clocks, again, are normally synchronized continually by the Mean Time Primary at the Observatory, though in case of accident to the synchronization wires they will still keep fairly good time by themselves. The Primary Clock at the Observatory is in turn daily corrected the fraction of a second found necessary by comparison with the Sidereal Standard, whose error is ascertained every few days by astronomical observations. In this way, barring accidents, every clock in the system always shows true time to within a fraction of a second. At present there are, all told, some 225 dials in operation ; in the immediate future the system is to be extended to the City Post Office, and to the group of buildings on Sussex Street—the Printing Bureau, the Mint and the Archives ; the three latter will be connected by underground wires and served by one master clock ; these additions will raise the total number of dials to fully three hundred. There has also been ordered, and is now ready for installation, a six-foot electric tower clock for the Post Office ; it will be equipped similarly to the one at the Observatory.

To give really efficient service with a system of this size, considerable expert attention is required ; most of the work in connection with the up-town service is now performed by Mr. Robertson of the Observatory staff. All apparatus and connections in the different switch-rooms are carefully inspected periodically, and the precaution is taken of making a monthly inspection of each separate clock. When we consider the pro-

verbial uncertainty of electrical apparatus in general, and the apparent *à priori* chance of failure of some one of the several successive operations by which the dials are worked—operations which are repeated some 40,000 times per month,—it becomes evident with what extreme care and delicacy every detail must be attended to, in order to ensure satisfactory working; that the working has been satisfactory, is evidenced by the decision to extend the system, as mentioned above, to include practically all the buildings owned by the Government.

In concluding this paper, I wish to express my sense of obligation to Dr. King for the consideration and encouragement which he has given me in my efforts to improve and perfect the Time Service, as well as for the valuable suggestions which he has frequently given me as to possible improvements and methods of working.

ADAPTING A UNIVERSAL SPECTROSCOPE FOR RADIAL VELOCITY DETERMINATIONS.

By J. S. Plaskett.

ONE of the chief lines of work planned by the Director in obtaining the instrumental equipment of the Dominion Observatory was stellar spectroscopy. It was hoped that satisfactory work in that line could be done with a fifteen inch telescope and a suitable spectroscopic outfit. Recent investigations by the writer have shown that such a telescope, with an efficient correcting lens, can successfully attack almost all the stars reached by some of the larger equipments, and that the field open to it for one particular branch of spectroscopic work, the determination of the radial velocities of stars, is a very wide one. Consequently the greater part of my time has been devoted to putting the instrument into satisfactory shape for the accurate determination of such velocities, and other spectroscopic work has only been partially touched upon. It is hoped however in the near future, when more assistance has been obtained, to broaden the line of research to include investigations into the spectra of stars of different types, into peculiar spectra, and into some parts of stellar spectra,—the region of longer wave length, now almost entirely unknown and untouched upon.

The principal radial velocity work so far undertaken has been the determination of the velocities of certain of the brighter stars, the so-called standard velocity stars inaugurated by Frost, and the determination of the velocity curves and orbits of some half dozen spectroscopic binaries. The chief value of the velocity determination of the standard stars in this case lies undoubtedly, as will be evident below, in the test they furnish of the accuracy of the spectrograph. That such tests were necessary will appear when I come to describe the process of putting the instrument into shape for accurate work.

Owing to preparations for and absence on the Eclipse expedition, and other work of a pressing nature, it was not until late in November, 1905, that any work in stellar spectroscopy was undertaken. It did not take long to discover that the instrument, as originally constructed, was unsuited for obtaining accurate velocity values. While it admirably fulfilled the purpose for which it had been designed, general spectroscopic work, radial velocity determinations require an altogether different type of construction, and it was inevitable that difficulties in the way of flexure should occur in the long exposures required in stellar spectra.

DESCRIPTION OF THE INSTRUMENT.

The spectroscope is of the universal type similar to those furnished by the same maker, Brashear, to the Lick, Naval,

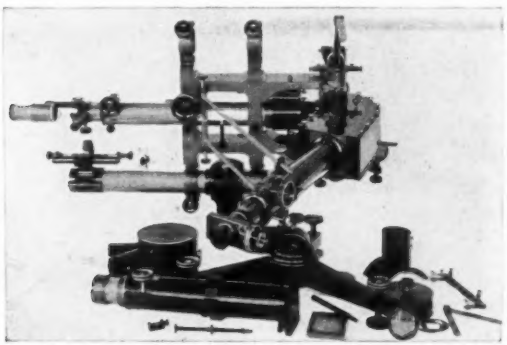


FIG. 1.

and Yerkes Observatories. It is arranged to be used both visually and photographically with the following dispersing media: (1.) A light flint prism. (2.) A dense flint prism. (3.) A train of three dense flint prisms. (4.) A plane grating. The instrument, which, with its various attachments, is shown in Fig. 1, with the prism train in place, is supplied with a swinging arm and rotating table, whose angular move-

ment can be read to half-minutes by verniers on a graduated circle. This adapts it for use as a laboratory spectroscope and spectrometer. The whole instrument is thoroughly well made and serviceable for a great variety of general work, but, as previously stated, the universal construction is one which is least adapted for use where the great stability and rigidity required in stellar velocity determinations is necessary. For that purpose the universal form has been entirely abandoned elsewhere, and spectrographs of the most rigid possible construction have been obtained in which all universal features have been sacrificed to stability, and which make photographs of star spectra only in one region of the spectrum. Until such a spectrograph could be obtained here, I undertook the task of so modifying the present instrument as to render it serviceable for accurate radial velocity work, with what success will hereafter appear.

The dimensions of the optical parts are as follows:—The collimator objective is of 15 inches focus and 1¼-inch aperture, but diaphragmed to slightly over an inch, to have the same angular aperture as the system of objective and correcting lens. The camera is of 15 inches focus and 1¼-inch aperture. The train of three prisms has been the sole dispersing medium used in radial velocity work, the prisms of which are of such dimensions as to transmit the full beam from the collimator, and are made of dense flint glass whose index of refraction for H_γ is about 1·64. The refracting angle of each prism is about 62° 30′, which gives a total deviation for H_γ of about 160°. The resolving power at H_γ is about 40,000, the purity with a slit 0·025 mm., the normal width used here, is slightly over 8,000, and the linear dispersion 18·6 tenth-metres per millimetre.

ADJUSTMENT OF THE SPECTROSCOPE.

In placing a spectroscope in adjustment, three points require careful attention:—(1.) The collimator focus. (2.) The camera focus. (3.) The adjustment of the prisms to minimum deviation. Of these, in my opinion, the exact focussing

of the camera is, for reasons that will appear later on, by far the most important in radial velocity work.

Collimator Focus.—Three methods of determining the collimator focus were employed, Schuster's*, Lippmann's†, and Newall's‡, with fairly accordant results.

Schuster's method consists in placing the observing telescope at a greater deviation than the minimum, and so changing the focus of the collimator and observing telescope that the line at minimum will be in sharp focus in the two positions of the prism that bring it into the field. This gave good values, the mean collimator setting being 15·6 mm., successive determinations differing by 0·2 mm. only. Lippmann's method, depending on the displacement of the two halves of the pencil by two plane parallel plates placed obliquely, and the consequent doubling of the spectral lines when the emergent beam is not parallel, seems by no means so sensitive and accurate as Schuster's. Newall's method, as my experiments have shown, is more applicable to the exact determination of camera focus. Any deviations of the collimator focus to the extent of nearly 2 mm. on either side could be so compensated by changing the camera focus as not to be evident by the displacement of the lines he speaks about.

The only observable change in eight series of test plates at eight collimator settings between 14·0 and 17·5, with six plates in each series at six camera settings near the focus, was in the length of field in good focus, which was the greatest at setting 15·0 and 15·5 with a slight advantage to 15·0. This was taken as showing, not that 15·2 was the focus of the collimator, but that at that focus the curvature of field of the camera lens was reduced to a minimum. I believe that 15·6, the setting determined by Schuster's method, is nearly exact, but that, by moving the slit away from the lens, a greater length of spectrum can be brought into focus. Hence the final setting was fixed at 15·2,

* *Phil. Mag.*, (5), vol. 7, p. 95-99, (1879).

† *C. R.*, vol. 129, p. 569-570, (1899).

‡ *M. N.*, vol. 57. p. 572; also vol. 65, p. 642.

and, as the changes in focus due to temperature are very slight, it remains at that setting.

Focus of Camera.—The accurate focussing of the camera is in my opinion much more important than that of the collimator. Here one cannot depend upon the test of definition, as the focus may be changed through a half-millimetre, an amount fatal to accuracy in line of sight work, without appreciably affecting the sharpness of the lines. The method employed here of obtaining the camera focus was evolved from Newall's method of focussing the collimator, a somewhat similar method being described by Hartmann*, and the focus is tested on every night the spectroscope is used. The method depends upon the displacement of the spectral lines on a plate not in focus when the pencil which forms them has its centre of intensity separated by a sensible distance from the centre of the objective.

Practically, the procedure is as follows. By a pair of diaphragms or windows situated close in front of the slit, which will be presently described, two spectra can be made side by side on the same plate, or rather one spectrum about 0·3 mm. wide along the centre of the plate has on each side a spectrum about 1 mm. wide. These spectra touch each other so that when there is no displacement of the lines they appear continuous, but the slightest displacement is at once apparent. Below the collimator lens is an opening in which a brass plate slides. This plate has a rectangular opening about 12 mm. wide and 30 mm. long, and the position of this opening is regulated by stops, so that in one position it allows a pencil of light of half the aperture to pass through the prisms near the refracting edge, and in the other position near the base. The middle spectrum is made through the refracting edges, and the outside spectra through the bases of the prisms. Hence the centres of intensity of the two pencils through the camera objective are separated by about 12 mm., and if the camera is not in exact focus the lines of the spectrum will not be con-

* *Astrophysical Journal*, vol. XII., p. 45.

tinuous. The method is so sensitive that, if a plate is 0·05 mm. distant from the true focal plane, a displacement of the lines is noticed. The camera was originally furnished with a plain index and scale reading to millimetres only, but it was found necessary to rule and apply a vernier to read to tenths, and to estimate to twentieths of a millimetre. The importance of accurate focus in line of sight work cannot be too highly emphasized, for, as the method outlined above shows, any inaccuracy of focus will result in a relative displacement of the star and comparison lines whenever, as often happens, the centres of intensity of the illumination pattern of star and comparison light do not exactly coincide.

Adjustment of Prisms.—Instead of using the minimum deviation device attached to the prism train and allowing any part of the spectrum to be brought into the centre of the field, the prisms were placed so that the ray H_γ was central and then rigidly fastened*.

MODIFICATIONS AND ADDITIONS.

The greatest difficulty encountered was that of flexure of the parts, but, in order to guard against every possible chance of systematic displacement, the whole instrument was thoroughly overhauled and changes made wherever it was thought any error could occur. The principal alterations were in the slit diaphragms, the slit, the comparison apparatus and in the addition of various trusses to overcome flexure. These will be described briefly in turn.

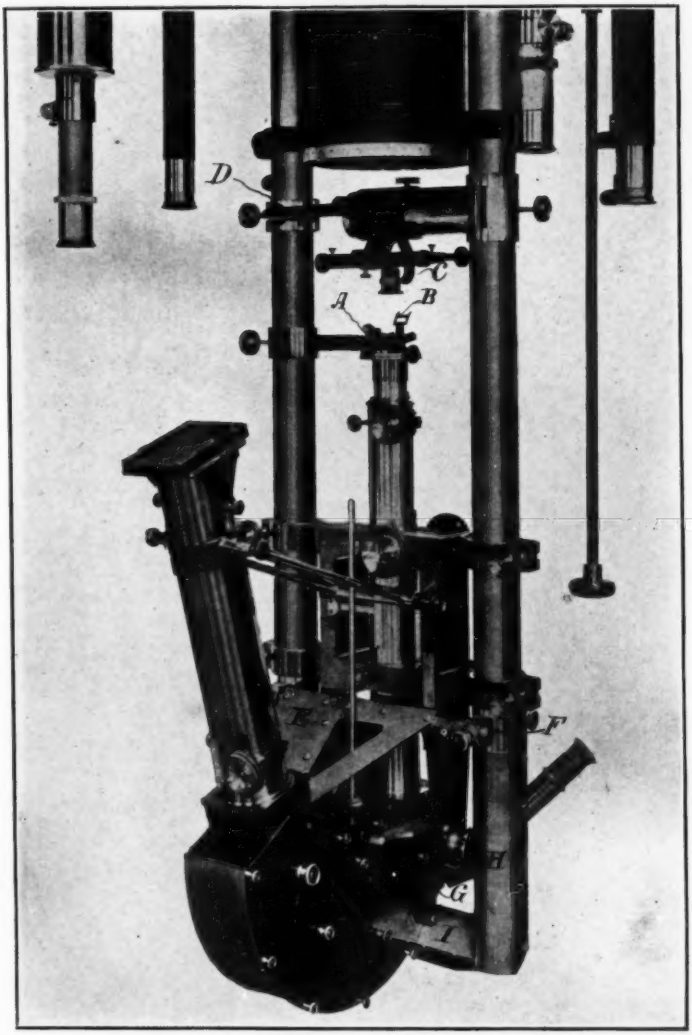
* Screws passing through the top of the box and pressing on the top of the prism cells are provided for clamping the prisms in position, but sufficient pressure for this purpose will induce unequal strains in the glass and affect the definition. As the collimator and camera lenses are corrected for H_γ, the camera and train were placed to make this ray central, and screws were inserted through the base of the box and the arms of the minimum deviation link-work, clamping the cells firmly to the base without fear of inducing strains in the glass. The strips on the bases of the cells, defining the positions of the prisms were loosened, and the prisms re-adjusted for minimum deviation. After the strips had been tightened, the top plates supplied with cork washers bearing on the prisms, were so adjusted as to introduce only sufficient pressure to hold the prisms in an invariable position without affecting the definition.

The Slit Diaphragms.—The diaphragms provided in front of the slit for making star and comparison spectra of the right width and in the right position were a modification of Hartmann's device*, and were attached to the slit head. To change from the opening through which the star was exposed to the opening for the spark, the brass plate containing these openings was moved between adjustable stops. As displacements of the lines were sometimes noticed in two spark spectra taken side by side through these windows, it was feared that the sliding of this brass plate might induce strains in the slit. This arrangement was dismounted and that shown at *A*, Pl. IV., was made to replace it. There are two separate diaphragms, one for the star light, *B*, having an opening about 0·3 mm. wide in the centre, all the rest of the plate over the slit being cut away except two narrow bars about 0·2 mm. wide to limit the star light. This was done for convenience in setting on the slit and guiding. The diaphragm for the spark light, has two openings each about 1 mm. wide, separated by an opaque bar, about 0·35 mm. wide, which is central and occupies the same position on the slit as the opening for the star-light. These are mounted on adjustable pins so that either can be readily turned down in position, while the whole arrangement is mounted on an arm clamped to one of the supporting tubes, as shown in the figure. It can be placed at any desired distance in front of the slit, or at once moved away to leave the slit entirely free if desired. It does not touch the slit or slit head at all, and hence all chance of displacement of the lines from this cause is avoided. It is also much more convenient in use than the old arrangement. The window for the star light is only turned down at first to get the star image central, and occasionally throughout the exposure to ensure that the required width of spectrum is being uniformly exposed.

The Slit Jaws.—In the tests for flexure to be presently described, I noticed that, even when there was no movement of

* *Astrophysical Journal*, XII., p. 46.

PLATE IV.



THE UNIVERSAL SPECTROSCOPE
AS ADAPTED FOR RADIAL VELOCITY WORK.

Journal of the Royal Astronomical Society of Canada, 1927.

the telescope and spectroscope between the exposures of the adjacent spark spectra, one made through the star, and the other through the spark windows, there was sometimes a displacement of the lines of one spectrum with respect to the other. After the diaphragms had been changed as above described this could only be due either to the slit or the comparison apparatus. An examination of the slit jaws showed that they were not brought to a sharp edge but consisted of two flat vertical surfaces about 0·7 mm. wide. One could not say what part of such jaws acted as the source of light, the focus would be uncertain, and trouble might arise from reflections between these flat and nearly parallel surfaces. The slit was taken apart, the jaws bevelled off to a sharp edge and ground perfectly straight. Great care was taken to ensure that the edges of these two jaws lay in one plane perpendicular to the axis. Even when this had been finished a photographic test by adjacent spectra showed occasional displacement of the spectral lines, and there only remained the comparison apparatus to be examined as the cause of the trouble. I may say that this work was done previous to the evolution of the focussing method above referred to, so that the camera focus may have been inexact to the extent of three or four tenths of a millimetre. This amount of displacement of the sensitive surface from the focal surface is quite sufficient to cause a marked displacement of the spectral lines, provided there is any faulty centering of the star or spark light.

The Comparison Apparatus.—The iron spark has up to the present time been used for the comparison light, the energy being supplied by a Queen 15-inch spark coil with a capacity, in parallel, of six half gallon jars. The spark gap was originally mounted to one side of the collimator tube, the spark light being reflected into the slit to one side of the light from the star or source to be examined, by a small diagonal prism. This was changed to a direct mounting of the terminals and condensing lens in the optical axis of the collimator about 80 mm. above the slit, as shown in *C*, Plate IV. When the star spectrum was being photographed the apparatus was swung to one side and

to ensure it being brought back to the same position, a stop, *D*, was clamped to the other supporting tube.

The angular aperture of the condensing lens is much greater than that of the collimator and this should, theoretically speaking, ensure the uniform illumination of the collimator objective even if not in exact adjustment. However it was feared that the spark gap might not always return to exactly the same place, and besides, the spark terminals were parallel to the slit, which is open to objection. The whole apparatus was therefore remodelled, the terminals and holders being shortened, made more compact and placed transversal to the slit. Then, with the condensing lens, they were mounted on a brass plate swinging between centres rigidly attached to one of the supporting tubes. When not in use it was simply tilted up out of the way, and when brought down again was absolutely certain to come back to the original position, so that when once in adjustment it would stay in adjustment To render the illumination more uniform a small piece of finely ground glass was placed about midway between the spark and the condensing lens, a position which extended trial showed to be best.

After these changes in slit, slit diaphragms and comparison apparatus, there was no further displacements of the spectral lines in adjacent spectra made one after the other, even with considerable mal-adjustment of camera focus, so long as the telescope and spectroscope were stationary. Any movement of telescope and spectroscope however, was at once followed by a displacement of the lines, undoubtedly due to flexure of the spectroscope.

Flexure of the Spectroscope.—Flexure of the parts was the greatest difficulty encountered. Owing to the design of the instrument the prism box has no adequate support. It is fastened by a single screw to the rotating table, which carries the grating or the single prisms, and which from its nature cannot be rigid. It is further secured by two rods reaching down from the box and clamping to the edge of the divided circle, which is a thin ribbed plate of brass not sufficiently stiff to furnish much support

to the prism box. The outer end of the prism box, which carries the camera, is entirely unsupported and could be moved by a pressure of the hand three or four millimetres to one side or the other. I had always suspected that flexure might cause trouble, but had no idea, until I made a test, of the extent of the displacement of the spectral lines that would be caused by a movement of the telescope with spectroscope attached through two hours in right ascension, the duration of an exposure on a faint star. The test was made in a similar manner to those above described, by making a spectrum of the iron spark through the star diaphragm, and, after moving the telescope, a second adjacent spectrum through the comparison diaphragm. Any shift of the lines due to flexure will at once be shown, and the shifts at first were very marked. A movement of the telescope through two hours showed in some declinations a displacement of the lines eqivalent to a velocity of 20 kms. per second. A rotation of the spectroscope of 90 degrees around the optical axis, when the telescope was at hour angle 0^h, declination 0^o, showed a shift equivalent to about 50 kms. per second. These figures at once showed that it was necessary to stiffen the parts wherever possible. The frame work of the instrument consists of a hollow built-up structure of rectangular section, seen in the illustrations, which is fastened by four hinged clamps to the two supporting tubes of the adapter. The collar into which these tubes fasten can turn on an inner collar, which screws into the eye end of the telescope. The two tubes are of 1⅞ inches diameter, of steel thick enough not to bend appreciably under the weight of the spectroscope. It was thought preferable to attach any stiffening trusses direct to these tubes rather than to the spectroscope frame which is not rigid enough for that purpose. The first truss made, shown at *E*, Plate IV., was built of thick sheet brass screwed to a brass rod which entered into clamps on each tube directly below the spectroscope frame, one of the clamps being shown at *F*. This triangular shaped brass plate, which had a second plate screwed at right angles underneath, extended diagonally across the back or base

of the prism box almost under the third prism. It was firmly screwed to the base of the box and served to prevent flexure at the outer edge of the prism box and the lower end of the camera. The upper end of the camera was provided with a brace, but this was further stiffened by a diagonal connecting rod. The prism cells, as before mentioned, had already been firmly clamped to the base of the box so that no displacement could arise there.

So far as stiffness of the outer end of the prism box is concerned, the spectroscope was immeasurably improved by this truss. A test of the displacement showed that the flexure had been much reduced, as a movement of two hours caused a displacement equivalent to about 5 kms. per second.

This was still too great, and a careful examination showed that it was probably due to a movement of the collimator end of the prism box, which was only supported by one projecting arm of the frame work. A built-up brass T-piece of suitable thickness was inserted between the other projecting arm, to which it was firmly screwed, and the top of the prism box. The arms of the T were made sufficiently long to extend to the outer walls of the box to which they were also screwed, the upper plate not being thick enough to form much support. The introduction of this piece further stiffened the instrument and resulted in a reduction of the displacement to an amount equivalent to between 2 and 3 kms. per second.

As this displacement was still rather great, I removed the swinging arm, which carried the telescope or camera when used with the single prisms or grating, the verniers on the circle and other small attachments. Two pieces of two inch brass tubing were bored out to fit the projecting ends of the 1⅞ inch supporting tubes, and these, one of which is shown at *H*, were firmly joined at their lower ends by a rigid U-shaped truss *I*, built up of brass plate to which the outer edge of the prism box was screwed. The projecting arms of the frame work were also firmly attached to the tubes *H*, while the prism table and divided circle were rigidly

connected together by a screw and block. The whole instrument with these additions seemed now very rigid, and a test showed that the displacement of the lines due to flexure was now reduced, at the most, to an amount equivalent to from 1 to 2 kms. per second for two hours movement while in some declinations of the telescope the flexure was hardly appreciable. This amount of flexure would not affect the final result by half the velocity mentioned, owing to the displacement being compensated to a considerable extent by a similar displacement of the comparison lines which are exposed for half the time before, and half after the exposure on the star. As I could contrive no further means of stiffening the instrument without rebuilding, it seemed preferable to keep it intact for work on other parts of the spectrum and to make all velocity determinations with an instrument of more modern type, designed expressly for line-of-sight work, and now nearing completion in our workshop.

The Temperature Case.—It was realized from the first that it would be necessary to provide some means of keeping the instrument at constant temperature during an exposure, for not only does the deviation and dispersion of the prisms change with change of temperature but the expansion of the metal parts would also be liable to introduce differential displacements of the star and comparison lines. The errors thereby introduced in velocity determinations might be comparatively large owing to the small displacements measured, one millimetre being equivalent to about 1300 kms. per sec.

A light wooden case enclosing the whole spectrograph was constructed and supplied with coils of German Silver wire for heating. The heat was at the beginning automatically regulated by a makeshift thermostat arrangement but this was finally abandoned for simple hand control by turning current on and off the coils. In the new spectrograph an automatic arrangement modelled after that by Hartmann will be employed.

The Correcting Lens.—After the thorough tests and the modifications and additions just described, I expected to get results

free from systematic error, but star spectra made with the instrument still gave velocities up to and sometimes greater than 2 kms. per second different from the mean of the values obtained by other observers of the same star.

Knowing that such differences could not be due to accidental errors of measurement a close search was made for the seat of the trouble, and it was found to be due to the fact that the star light was distributed irregularly and unsymmetrically over the collimator and camera lenses. The slit was placed in all positions, both at and near the apparent star focus and at a considerable distance within and without, but in no position could the illumination be made even approximately uniform. The position of the correcting lens was altered in each direction without any improvement, and the lens itself was inverted in its cell, which made matters worse. Acting on a suggestion of Dr. R. H. Curtiss, of the Allegheny Observatory, to whom I am indebted also for other help, I made a double slide carrier for the correcting lens, adjustable from the eye-end, which allowed the lens to be collimated exactly by means of a bright star, but this gave no useful result.

It was noticed, when the slit was very narrow, that the illumination became more uniform, which was likely due to the diffractional spreading of the light. Furthermore, when the slit was made 0·2 mm. wide the illumination was uniform, the inference being that with a slit of this width the entire star image was transmitted while with a narrower one part of the image was cut off by the jaws. Indeed the star image seemed to have a core about 7″ in diameter which was much too large, and pointed to some defect in objective or correcting lens, or both. This was also indicated by the very long exposures required to obtain measurable spectra.

The difficulty was narrowed down and shown to be in great part due to the correcting lens. At H_γ more than twice as much exposure was required when the correcting lens was in place as without it, showing that it apparently increased the diameter of the image. This was shown also by measurements

of the width of spectra made with the slit in different positions in the neighborhood of the star focus. The spectra were made linear by using a bright star, Vega, by opening the slit to half a millimetre wide, and by turning the spectroscope until the slit was parallel to an hour circle so that irregularities in driving would not widen the spectrum. The widths with the correcting lens were never less than 6″, and moreover did not change much as the slit was moved within and without the focus to the extent of 6 mm. on each side. Some of the out-of-focus spectra had a condensation in the centre, with diffuseness at each side of the strip, the whole appearance being decidedly characteristic of spherical aberration. In the spectra made without the correcting lens the width was about 3″, and with no evidence of condensation at the centre in the out-of-focus parts.

The trouble, as stated above, was diagnosed as possibly due to spherical aberration, and the correcting lens was taken out of the cell and examined carefully. There were apparently no defects in the surfaces, for, so far as could be seen without specially testing, they were all spherical. One cause of the trouble might be the wrong placing of the elements in the cell, for if one of the elements were inverted it would probably introduce sufficient spherical aberration to cause the observed effects. The lens consisted of a double equi-convex, presumably of flint glass, and a double concave of crown. The curvature of the outside surface of the concave was the same as that of the convex, while the inside surface, against the convex lens, was of greater curvature. As it seemed possible when one of the surfaces of the concave was of the same curvature as the convex, that it had been intended to place them together, the paper separators were moved to the other side and the concave inverted so that the contact surfaces faced each other.

This seemed to remove the difficulty, for the illumination pattern on the collimator and camera lenses was now found to be practically uniform for all slit widths, and had the same appearance as that given when the correcting lens was removed. While

the necessary exposure required to get measurable star spectra was diminished by more than one-half.

So far as regards the removal of systematic error due to the eccentric position of the centre of intensity of the star light, the negatives made since, so far as measured, show no signs of such error, but give accordant results.

However, the results of a later extended quantitative investigation into the character of the star image in spectrographic work, which will appear in this JOURNAL*, shows that there is still considerable residual spherical aberration. The investigation shows, moreover, that this is due to the chromatic differences of spherical aberration of a visual objective used photographically, not being compensated for by the correcting lens, and indicates the possibility of a considerable advance, so far as regards the efficiency and range of the spectrograph, by the introduction of a suitable correcting lens. A comparison of the performance of existing spectrographic equipments shows that others are probably affected in the same way, and an improvement here suggests the possibility of a similar improvement elsewhere.

Although the various difficulties encountered in making the spectroscope suitable for accurate velocity determinations have prevented as much work being accomplished as could otherwise have been done, they have not been without advantage, for they have certainly formed an education on spectrographic peculiarities and causes of error, which could not otherwise have been obtained. The new spectrograph, which I have designed especially for radial velocity work, and which is now being constructed in our workshop, is so arranged that it is hoped all the difficulties above detailed will be more completely overcome or avoided than has been possible with the present instrument, and that it will prove to be very efficient for determinations of velocity in the line of sight.

* Also in the *Astrophysical Journal*.

Feb. 22, 1906. Observed by J. S. Plaskett.
G.M.T., $16^h\ 15^m$. Measured by J. S. Plaskett.

Measured Wave Length	Normal Wave Length	Displacement	Velocity kms. per sec.
4582·970	2·634	·336	+21·41
4554·617	4·211	·406	26·72
4550·064	9·766	·298	19·64
4536·292	5·965	·327	21·61
4529·174	8·807	·367	24·30
4523·174	2·854	·320	21·22
4486·254	5·888	·366	24·45
4476·549	6·214	·335	22·41
4473·338	2·957	·381	25·53
4467·143	6.771	·372	24·96
4459·683	9·304	·379	25·47
4448·253	7·892	·361	24·30
4442·947	2·510	·437	29·45
4427·807	7·420	·387	26·20
4415·681	5·293	·388	26·34
4405·250	4·951	·299	20·33
4395·623	5·286	·337	22·95
4379·712	9·331	·381	26·06
4376·405	6·107	·298	20·38
4371·630	1·312	·318	21·81
4370·272	9·856	·416	28·53
4353·326	2·923	·403	27·72
4352·365	2·006	·359	24·74
4341·012	0·634	·378	26·08
4328·463	8·080	·383	26·50
4319·190	8·817	·373	25·86
4315·495	5·178	·318	22·07
4294·668	4·273	·395	27·57
4292·644	2·319	·325	22·69
4288·540	8·134	·416	29 04
4254·822	4·505	·317	22·34
4251·284	0·954	·330	23·27
4247·955	7·566	·389	27·42
4247·340	6·996	·344	24·25
4245·803	5·455	·348	24·56
4236·477	6·112	·365	25·80
4235·671	5·389	·282	19·94
4222·718	2·382	·336	23·82
4219·836	9·520	·316	22·44
4210·846	0·523	·323	22·97
4204·007	3·730	·277	19·75
4200·464	0·114	·350	25·03
4191·257	0·874	·383	27·38
4189·989	9·723	·266	19·01
4185·390	5·058	·332	23·77
4179·889	9·542	·347	24·87
4171·472	1·140	·332	+23·84

Mean +24·61

$\epsilon = \pm 2·67$ Va −19·59
$\epsilon_m = \pm 0·38$ Vd − 0·14
Curvature − 0·50 − 20·23

Radial Velocity +4·4

i.e. a recession of 4·4 kilometres per second.

COMPARISON OF RESULTS.

Star	Dominion Observatory			Other Observers			
	Plate No.	Date	Velocity	Observer	Velocity	No. of Plates	Range
β Geminorum	196	Feb. 22	+4·2	Frost	+3·2	3	0·6
	197	Feb. 22	4·4	Adams	3·7		0·2
	212	Mar. 5	3·8	Lord and Maag	5·3	5	5·4
		Mean	+4·1	Belopolsky	3·4	9	1·4
		Range	0·6	Newall	2·0	6	3·0
				Slipher	3·3	3	0·2
α Bootis	199	Feb 22	− 4·2	Frost	− 4·7	5	1·3
	216	Mar. 5	5·6	Adams	4·9		0·9
	220	Mar. 23	4·6	Belopolsky	6·1	9	3·3
	230	Mar. 28	4·7	Lord and Maag	3·2	7	3·2
	238	Apr. 2	5·2	Frost, Adams	4·3	8	1·8
	252	Apr. 24	5·5	Newall	5·8	5	2·7
	253	Apr. 24	3·4	Newall	6·6	19	4·5
	300	June 18	5·1	Slipher	4·7	5	1·4
	312	June 27	4·7				
	319	July 2	4·9				
	325	July 4 P.	3·3				
	325	H.	3·3				
		Mean	− 4·6				
		Range	2·3				
β Ophiuchi	327	July 4	−10·3	Frost	−11·3	3	0·8
	334	July 6	12·2	Adams	10·9		0·7
	353	July 18	11·7	Newall	15·8	2	1·9
		Mean	−11.4	Slipher	11·3	3	1·1
		Range	1·9				
γ Aquilae	323	July 2	− 2·0	Frost	− 1·4	3	0·7
	323	July 2	1·6	Adams	2·2		1·0
	329	July 4	1·3	Belopolsky	2·0	10	3·8
	335	July 6	1·8	Newall	1·9	4	4·2
	354	July 18	2·1	Slipher	2·1	3	1·4
	361	Aug. 1	1·3				
		Mean	− 1·7				
		Range	0·8				
ε Pegasi	370	Aug. 15	+5·0	Frost	+6·2	3	0·5
	400	Sep. 27	6·5	Adams	6·2		0·4
	409	Oct. 16	5·5	Belopolsky	6·0	7	1·4
				Newall	3·3	3	2·6
		Mean	+5·9	Lord and Maag	6·1	5	5·8
		Range	1·0	Campbell	5·7	4	1·2
				Slipher	6·1	4	1·8
α Arietis	331	July 4	−13·5	Frost	−13·5	3	0·8
	337	July 6	16·0	Adams	13·9		0·7
	364	Aug. 1	16·5	Campbell	14·1	4	0·6
	393	Sep. 10	13·7	Newall	14·3	3	2·8
				Lord and Maag	12·4	5	1·8
		Mean	−14·9	Lord	14·0	2	2·7
		Range	3·0	Newall	16·4	8	6·3
				Slipher	14·3	3	0·5

COMPARISON OF RESULTS, (*Continued*).

Star	Dominion Observatory			Other Observers			
	Plate No.	Date	Velocity	Observer	Velocity	No. of Plates	Range
α Persei	330	July 4	- 3·4	Frost	- 2·3	3	1·6
	336	July 6	0·6	Adams	2·0		1·3
	411	Oct. 16	2·3	Campbell	2·2	10	2·0
				Belopolsky	2·9	8	3·7
		Mean - 2·1		Lord and Maag	+ 0·6	5	3·7
		Range 2·8		Newall	- 2·6	14	5·7
				Vogel	3·2	13	3·3
				Newall	4·6	5	5·5
				Slipher	2·5	5	1·3

CONCLUSION.

As evidence of the success attending the improvement of the spectrograph there is inserted above, an abridgment of the reduction sheet of a spectrum of β Geminorum, showing the agreement between the velocities obtained for the different star lines. I also include a summary of the results obtained for seven of the "standard velocity stars," and, for convenience of reference and comparison, the values obtained by other observers so far as known to the writer, with the range or difference between the greatest and least velocity.

It must be remembered in comparing the Ottawa results with those of other observers that the dispersion of the instrument used here is about 40 per cent. less, thus increasing the relative error of setting on the lines; that our results were obtained from an adapted universal spectroscope which has never before been successfully used in radial velocity work, and finally that practically all the spectra here given were made within eight months of starting work on the spectrograph, the instrument during that period having been investigated and corrected in the manner detailed above.

It gives me pleasure to acknowledge here the able part taken by Mr. W. E. Harper in the observation of some and the measurement and reduction of many of the spectra and I am glad also of this opportunity of signifying my appreciation of the help and encouragement so readily given by Dr. W. F. King, Director of the Observatory, in the prosecution of the work.

MAGNETIC DISTURBANCES RECORDED AT THE AGINCOURT OBSERVATORY.

By R. F. Stupart.

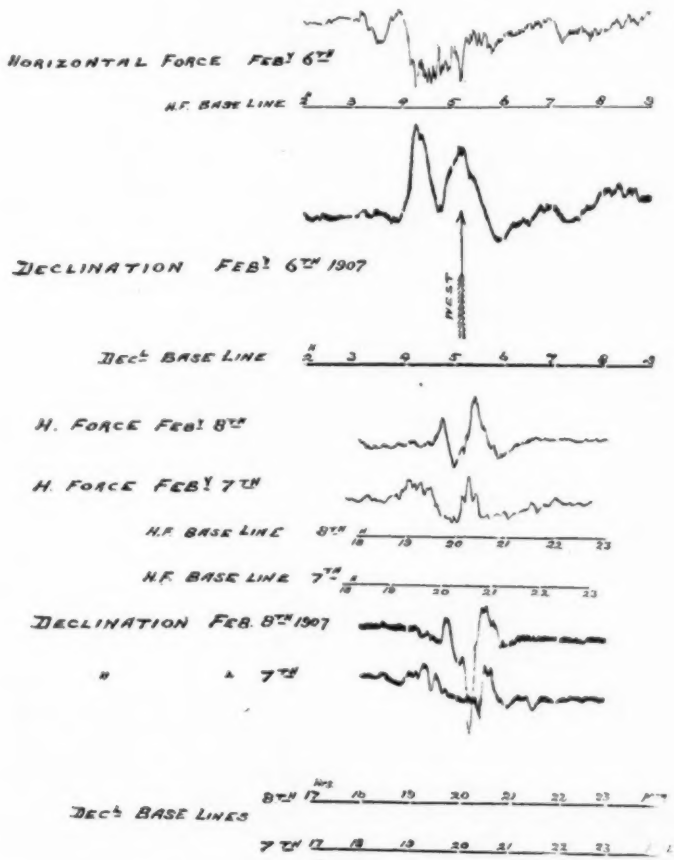
A SERIES of magnetic disturbances were recorded at the Agincourt Magnetic Observatory February 6–9, 1907, during which period the sun showed remarkable disturbances as evidenced by spots, and some very beautiful auroræ were observed in various parts of the Dominion.

The magnets were somewhat disturbed after 21^h February 6, and small movements continued during the night. At 3^h 56^m on the 7th the declination needle began a westerly movement, and in 21 minutes had passed through an arc of 45′·2. A sharp return movement followed lasting for 29 minutes, when another abrupt westerly movement occurred through an arc of 28′, and then a somewhat slower easterly movement, which by 4^h 43^m gave a declination 10′ east of that recorded at 3^h 56^m. By 9^h 30^m the magnet was steady at a nearly normal position.

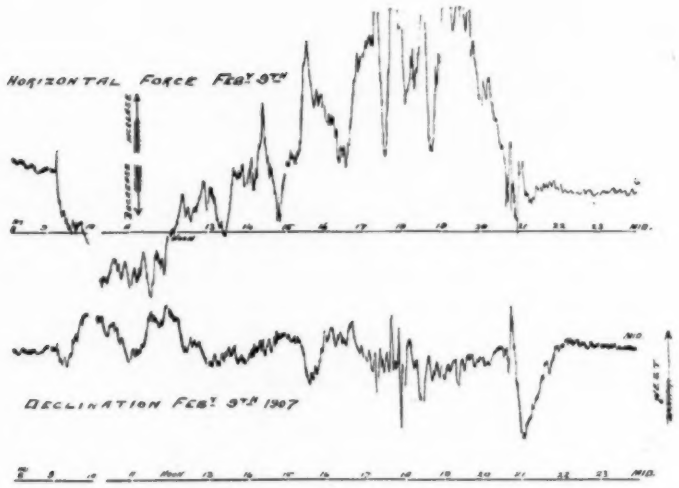
The movements registered on the evenings of the 7th and 8th were quite remarkable. They had somewhat similar characteristic features, and occurred at approximately the same hour on consecutive days. On the 7th the extreme easterly reading was reached at 20^h 29^m and the extreme westerly at 20^h 35^m 7^s, and on the following day the extreme easterly at 20^h $14{\cdot}4^m$ and westerly at 20^h 30^m, a change of 56′ occurring in 14·5 minutes. Several irregular movements of both the declination and the horizontal force magnets occurred during the early hours of the 9th, and then suddenly at 9^h $10{\cdot}5^m$ a disturbance of large dimensions set in. Until about 14^h the force was below its normal value and afterward generally above for seven hours, during which interval the bifilar magnet made some eight large excursions, and in five instances the record was beyond the limit of the paper. The largest movement in declination occurred

between 20^h 43·6^m and 21^h 0^m, when a change of 1° 4′ was recorded.

The changes above described are shown by the accompanying diagrams.

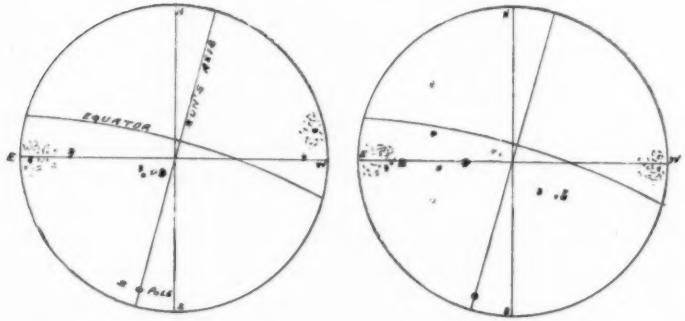


Disturbed Magnetic Curves, February 6, 7, 8, 1907.
Agincourt Station of Toronto Observatory.



Horizontal Force and Declination Curves for February 9, 1907.

Scale for H. F., 1 mm. = 0·000207 dyne;
for Decl., 1 mm. = 5′·88.



Feb. 6, 1907, 12 h 15 m. Feb. 8, 12 h 40 m, E.S.T.

The Sun's disc as sketched with the 6-inch refractor of the Toronto Observatory.

THOUGHTS ON METEOROLOGY AND TERRESTRIAL MAGNETISM.

By Andrew Elvins.

ALL are interested in meteorological changes and wish to learn the reasons therefor. We know that summer and winter are caused by the northern hemisphere being turned towards or away from the Sun, but we fail to see why one summer should be hotter or one winter be colder than another.

It has long been known that sometimes the Sun's surface is covered with spots, sometimes quite free from them, and Schwabe found that they had a periodicity, an irregular one, it is true, but averaging in length between 11 and 12 years. Dr. Lockyer has found a period of something more than 30 years. May not our meteorological conditions be dependent on these solar variations?

Terrestrial magnetism undergoes changes which synchronize with those of the sun-spots. The curve showing the variation in the mean daily declination is precisely similar to that exhibiting the 11-year sun-spot period. What can cause this coincidence?

Again, the terrestrial magnetism suffers a long secular variation. At London in 1580 the north end of the needle pointed 11° 15′ East of North; in 1622, 6° E.; in 1660, due N. Then it began to point westward, increasing until it reached its maximum, 24° 41′, in 1820. Since then it has returned eastward and is now about 16° W. of north (at London).

This long variation appears to be due to a revolution of the magnetic pole about the terrestrial pole, and from due north to extreme west would seem to be one-fourth of a cycle. This was accomplished in 160 years, giving four times this, or 640 years, for a complete period.

I have long thought that the falling towards the sun of cosmic matter from all parts of space within his sphere of influence would account for many solar and terrestrial phenomena. The attractions of the planets on this matter would produce meteor swarms and the passage of the earth through these might produce magnetic variations. Since these meteoric streams would be largely dependent on Jupiter, Saturn and Mars, the period of the magnetic variations should in some way depend on the periods of these planets. If these planets all act in the same manner, the product of the three periods would be the time from one conjunction to the next. The periods of Mars, Jupiter and Saturn are 1·88, 11·86 and 29·46 years, respectively. The product of these three numbers is 656·77—nearly the same as a magnetic cycle, quite as near to it as we should expect from the uncertainty of the magnetic data. To me it seems probable that one is the cause of the other or both are due to a common cause.

MEETINGS OF THE SOCIETY

AT TORONTO.

February 19.—The following were elected to membership in the Society :

F. C. Neal, M.A., M.D., Peterborough ;
Lachlan Gilchrist, M.A., University of Toronto, Toronto.

Reports were made that a fine aurora was seen on the night of February 11, and a fine meteor in the western sky in the early evening of February 18.

Two papers were given, the first by Mr. J. Edward Maybee, M.E., on " A Comparison of Lunar and Terrestrial Volcanoes," and the second by Mr. R. Stewart Muir, on " The Use of Esperanto, the Universal Language, to Astronomers."

Mr. Maybee's address set forth briefly what had been learned as to the probable nature and genesis of lunar craters by a careful study of the various types of craters on the earth. Nasmyth's " eruption " theory, founded on a study of typical craters of the Vesuvian type, which has met with considerable favour in the past, seems likely to give way to the " engulfment " theory of later years, more particularly in view of Pickering's recent work on the Hawaiian craters. In connection with the latter one should read a chapter on lunar and terrestrial craters in his work on the moon, published in 1903. The Hawaiian volcanoes are mostly of the " lava type " as compared with the majority of terrestrial volcanoes, which are largely made up of ejected ashes, scoria, lapelli, lava bombs or mud. Steam is usually the motive power in eruptive volcanoes, whereas in lava craters little steam is present and the crater walls are built up by comparatively quiet outflows of liquid lava. The water to form steam is and probably always has been very scarce on the moon, and for that reason alone it might be expected that lunar craters would not be of the eruptive type. In addition, the resemblances between the Hawaiian lava

cones and the lunar formations are so striking that it becomes almost a certainty that the same forces must have been at work in both cases. On the moon the force of gravity is only one-sixth of its force on the earth, and in addition, the earth's attraction on the moon is about eight times that of the moon on the earth, and in past ages was probably much greater. The immense tides thus created on the moon pumping liquid lava up and down through the cracks and crevices in the moon's crust would be quite sufficient to account for the immense size of the lunar formations. Mr. Maybee's paper was illustrated with lantern slides, chiefly from Prof. W. H. Pickering's recent work on "A Comparison of Lunar Features with those of Hawaii."

Mr. Muir gave an interesting sketch of the growth of the Esperanto language from its publication in 1887 by its author, Dr. L. Zamenhof; and explained how it is so admirably suited to international communication. In the realms of science and commerce Esperanto seeks its chief honors. Astronomers in various countries have taken advantage of it, and in the *British Esperantist* for December last appears an article by M. Felix de Roy, a Member of the Astronomical Society of Belgium, concerning the employment of Esperanto in astronomical work.

March 6.—It was announced that a meeting had been held in Victoria, B.C., with a view to establishing a Section of the Society at that place; also that at a largely attended meeting held in Peterborough on the 26th of February a local organization, intended to be a Section of the Society, was formed.

Three members reported having seen Mercury on March 2 at its recent eastern elongation, the maximum of which was 18° 10′, attained on March 1.

A note was presented by Mr. Andrew Elvins showing that the long secular variation of the magnetic needle at Greenwich has a period approximately equal to the periods of the planets Mars, Jupiter and Saturn multiplied into each other, both cycles being about 650 years. Mr. Elvins dates his study of the sub-

ject from communications made to the Toronto *Daily Telegraph* in 1868.

The paper of the evening, contributed by Mr. J. S. Plaskett, B.A., of Ottawa, was upon "Spectrographic Work at the Dominion Observatory." It will be found on page 104 of this JOURNAL.

March 19.—The following were elected to membership in the Society :

E. Baynes Reed, Meteorological Office, Victoria, B.C.

F. Napier Denison, Meteorological Office, Victoria, B.C.

Miss Margarethe J. Jensen, Ph.D., University of Toronto, Toronto.

Miss I. M. Walker, 116 George Street, Hamilton, Ont.

The paper for the evening was by Mr. Andrew Elvins, on "The Tides." Mr. Elvins recalled reading in the first edition of Chambers' "Handbook of Astronomy" an account of the tidal phenomena of Tahiti and the Society Islands*, and of his feeling that the explanation of the tides usually given did not satisfactorily account for the phenomena observed. He advanced the view that a chief cause of the tides is the so-called centrifugal force. When a rubber ball is fastened to the end of a string and made to revolve in a circle, the ball is strained approximately into a prolate spheroid with its axis in the same direction as the string. Mr. Elvins contended that the earth on account of its revolution about the Sun is strained into a prolate form, which is combined with that produced through its revolution about the common centre of gravity of the earth and the Moon. In this case the highest point of the protuberance should always be in the plane of the earth's orbit.

E. A. D.

AT OTTAWA.

February 14.—The paper for the evening was by Dr. Klotz on "Planetary Motions." With the aid of a 30-inch globe the lecturer showed the apparent daily motion of the stars and the

* See 3rd ed., vol. I., p. 368.

change of their paths across the sky due to change of the latitude of the observer. The meaning of the ordinary astronomical symbols found in the almanacs, even in patent medicine almanacs, was explained and by giving the derivation of the names they were impressed on the memory.

Then followed a brief historical sketch of astronomy from the times of Hipparchus and Ptolemy, and of the geocentric theory which prevailed for fifteen centuries. The fulfilment of prediction of eclipses seemed to afford evidence of the apparent truth of the belief that the earth was the centre of the universe. The great stumbling block for nearly twenty centuries was the proper interpretation of the apparent oscillatory motions of the superior planets, notably of Jupiter and Saturn which seem to move backward and forward amongst the stars. By means of a diagram of the motion of the earth and of Jupiter for the past two years which the lecturer projected on a screen, was shown very effectively how this apparent oscillatory motion is produced. By a similar diagram the apparent motion of Venus, as morning star and evening star, was shown.

Kepler's Laws were fully explained and illustrated and were shown to be included in Newton's Theory of Gravitation propounded a century later.

The lecturer closed with an eloquent description of the rearing of the Temple of Science on Newton's great theory. Each stone of the temple must be truly fashioned or it will be rejected by Observation, the pitiless critic. Sometimes stones must be removed, to be replaced by better ones.

"And what privileges," said the lecturer, "this temple accords us. We may wander about it and in it, explore and investigate all its chambers and apartments; if attentive we may learn how it was built, how each stone was fashioned, and we will learn to appreciate its symmetry and beauty. We will find that the workers, old and young, are all volunteers. Their incentive is the search for truth, and their reward the consciousness of honest labor performed. In course of time I hope that a stone will be found there, showing the hall-mark of this Obser-

vatory, as I am sure it will be found."

February 28.—Mr. R. M. Stewart presented in a clear and concise manner the results of an extended investigation on "The Comparison of Transit Observations with Key and Micrometer." He pointed out that the cause of the discrepancies in time observations with the transit key had always been attributed to irregular variations in personal equation. If this were so, then we should expect these discrepancies to disappear in transit micrometer observations. The result of his investigation of this question by a special series of observations, and also by a comparison of data available from previous observations, showed that the errors in the latter case are fully as large as in the former. While the apparent probable error of a good time set with a portable instrument, as determined by the concordance of the separate observations, is only about 0·012 sec., the real average liability to error amounts to 0·035 or 0·045 sec. The cause of this error he traced in great measure to the defective determination of instrumental corrections due to errors in the observations of polar stars. A partial remedy for this probably consists in abandoning the custom of balancing sets as regards north and south stars, and adopting the principle of observing polars of as high a declination as possible within reasonable limits, while choosing time stars as near the zenith as convenient. He concluded by intimating that a further investigation into this question was in progress.

The President in discussing the paper spoke highly of the work done by Mr. Stewart and briefly discussed the question of balancing observations from the standpoint of least squares. The Secretary also commended the enthusiasm and ability shown by Mr. Stewart in this investigation.

March 14.—Mr. J. S. Plaskett presented a paper on "The Optics of the Telescope."

After preliminary remarks on the nature of light and on the best means of attacking problems relating to the course of light through lenses, Mr. Plaskett chose the geometrical method, beginning with the fundamental conception of rectilinear propa-

gation. The law of refraction was illustrated graphically, and its application to transmission through prisms and lenses developed. By experiments were shown the course of a parallel pencil through convergent and divergent lenses, the production of images by the former and also the formation and viewing of images in a telescope. The graphical method of obtaining the position and magnitude of those images was explained, and the course of a pencil of rays was traced from the object through objective, real image, eye lens, and into the eye. The cause and remedy of chromatic aberration was explained and illustrated by experiments, the course of the light through an achromatic pair of prisms being shown. This chromatic correction in ordinary glasses, however, is only complete for two colors, and the cause of the secondary spectrum and its effect on astronomical observations was explained. Mr. Plaskett then referred to the means of removing this defect and the advantages of apochromatic objectives. Spherical aberration was explained and beautifully illustrated by the passage of a parallel pencil through a large converging lens, and the methods of overcoming both it and chromatic aberration at the same time were discussed.

Then treating the subject by the wave theory, the diffaction disc and rings at the focus of a telescope were explained and illustrated by slides. The dimensions of the central disc and the resolving power of telescopes of different dimensions were given. The lecture was closed by a short description of the methods used and the accuracy required in making telescope objectives, illustrated by samples of optical glass and lenses in different stages of the process, kindly supplied by Dr. Brashear.

Complimentary remarks were made by the Chairman, Dr. Klotz, and by Messrs. Joseph Pope and F. A. McDiarmid.

Since the last issue of the JOURNAL the following have been duly elected members.

A. C. Mitchell, Free Press Office.
Rev. J. S. Stewart, Marlow, Que.
C. H. Beddoe, Acct., Interior Department.
G. A. Mountain, C.E., Chief Engineer, Railway Comm'n.

J. S. P.

NOTES FROM THE DOMINION OBSERVATORY.

Boundary Surveys.—During a recent visit of the American Boundary Commissioner, Mr. O. H. Tittmann, to Ottawa, arrangements were made for the survey of the 141st meridian, in accordance with the treaty entered into with the United States last year.

The observations for longitude by the telegraphic method, which the treaty calls for were made last summer. A station on the bank of Yukon River, as near to the meridian as could be determined from the best available evidence, was occupied by Mr. F. A. McDiarmid, of the Observatory staff. There being telegraphic communication both ways from this point, east and west, a double determination was made, and corresponding observations were made by Dr. Klotz, at Vancouver, and by Mr. Smith, of the U.S. Coast and Geodetic Survey, at Fort Egbert, Alaska. The longitudes of these two base stations had been previously determined.

The longitudes determined for the boundary station from the two base stations differed about 27 feet, and, by combining them, the station was found to be $0^{s}{\cdot}027$, or about 17 feet, to the west of the true 141st meridian.

The Commissioners have decided to produce the meridian from the point thus determined, southward in the first place, and as rapidly as possible. There is an important mining region near the line, about the head of White River. This it is necessary to reach without delay. As it lies some 250 miles south from the initial point of the survey, it will be seen that the surveyors must make the best use possible of the short northern summer, if White River is to be reached this year.

Mr. McDiarmid left Ottawa some days ago for the Yukon, to take part in the initial operations of offsetting the lines and observing the initial azimuth, so as to save time for the line surveyors who will go in when navigation opens. A triangulation is to be carried along the line and a topographic survey

based thereon for two miles on each side. Monuments are to be placed along the whole length of the line, visible each from the next.

Arrangements were also made by the Commissioners for the continuation of the survey of the boundary line along the Coast (under the Award of the London Tribunal of 1903), and for that of the eastern section of the International boundary, between Vermont and Quebec.

The survey of the 49th parallel west of the Rocky Mountains being almost complete, it was agreed that a joint inspection of the monuments should be made this summer by the Commissioners, before final acceptance by them of the survey.

Preparations are being made by the Chief Astronomer for the energetic prosecution of the geodetic survey of Canada, as soon as the snow disappears. A description of the intended operations of the survey is reserved for subsequent "notes."

W. F. K.

Geodetic Survey.—For more than three decades this subject has received more or less attention from societies and corporate bodies directly or indirectly interested in similar work, or who have considered it worthy of their notice as involving scientific investigation. Our Government has recognized its importance, but until quite recently no encouragement has rewarded the efforts of those who are in a position to carry on the work. That the development of our country has reached a stage when a triangulation survey is imperative, has been amply demonstrated by the increasing number of urgent requests for geographic positions in various parts of the Dominion. Isolated stations without co-ordination are necessarily astronomic and do not indicate geographic positions with sufficient accuracy for precise surveys.

After many earnest and lengthy consultations it was decided in June, 1905, that a primary triangulation must be commenced at once, and prosecuted with a vigour commensurate with the means at our disposal. On the 27th of that month, Dr. King the Chief Astronomer, and the writer, went to the summit of

King Mountain, the most prominent elevation in the Laurentian Range contiguous to our Observatory and determined the azimuths of culminating points within their horizon.

On July 2, the first signal was erected on that mountain, and since that date a signal building party has been continuously engaged during suitable seasons erecting the high tripods and observing scaffolds necessary to overcome the topographical obstacles between the stations chosen. As these observing towers are from seventy to ninety feet high this branch of the work is tedious and requires men especially trained for it. Good progress has been made and during the present season we intend occupying the stations now ready as well as those which will be built in advance of the observing party.

Recognizing the advantage of the absence of leaves from the forests, the rigors of our Canadian winter have been braved and reconnaissance work pushed to the eastern boundary of that portion of the Province of Quebec south of latitude 45° 40′. Snow furnishes additional light for long distance optical work, but its great depth upon the sides of the mountains made the work of climbing them somewhat strenuous. The nature and scope of the triangulation survey will be fully described at the meeting of the Ottawa Section on March 28th at 3 p.m.

C. A. B.

Astrophysics.—Observations for the radial velocities of spectroscopic binaries are being continued regularly. Of those mentioned in the previous note, α *Draconis* is completed and the elements of its orbit determined. They are :—

Period, 51·42 days.
Eccentricity, 0·322.
ω , 20° 3.
m_o, 294°.
Time of periastron passage, T, 1906 July 11 d 4 h.
Velocity of system, V_o, − 18·4 km. per sec.

Considering the few lines and the character of the spectrum, the observations fall very close to the curve and the elements though only provisional will not probably be much changed by future observations.

The case of *η Piscium* is an example of the desirability of measuring and reducing observations as soon as possible after making the plate. This star was put under regular observation here early in the autumn but no plates could be measured until recently. The measurements show that, although there is no doubt of its binary character, the period is much shorter than was supposed and the star is now too near the sun to definitely finish the work. Had the plates been measured earlier the observations could then have been arranged to obtain a satisfactory curve without waiting until it again reaches a position where it can be observed.

The new spectrograph is now practically completed, the temperature case being the only part so far untouched. The temperature is to be controlled by a pair of electric contact thermometers arranged somewhat similarly to the method employed by Hartmann. If it is found necessary, a small fan will be attached to keep the air in circulation and prevent stratification. The spectrograph gives every promise of being very rigid and stable, and this, with thorough temperature control, should enable the highest class of work to be produced.

The plans and specifications of a shelter for the horizontal cœlostat telescope are complete and the building is to be erected in the early spring. The secondary plane and the concave mirror are completed and stored in our instrument room, and it is hoped to have the instrument in regular use during the summer in solar research work.

J. S. P.

The Time Service.—The outside heat-proof case for the Riefler Clock has been installed, and is now heated independently of the rest of the Clock Room. It is so divided by means of a partition that a small fan keeps up a continual circulation of air through an electric heater and throughout the case ; the heater is controlled by the Callendar Recorder in the Time Room. The temperature is thus kept at a much more constant value than has hitherto been possible, and the result should be decidedly beneficial to the clock-rate, especially as

there are indications that the pendulum compensation has not exactly the proper valve.

The result of the comparison of transits with the key and the travelling wire micrometer is mentioned elsewhere in this JOURNAL ; the cause and remedy for the abnormally large liability to error is still a matter of investigation. The test of the rate of the Riefler Clock afforded by that series of observations was fairly satisfactory, though a slight change in the temperature of the clock was accompanied by a change in rate of about a tenth of a second per day. During nearly a month when the temperature was constant, the largest observed variation from perfect regularity was about 0·05 sec. Now that the temperature can be kept accurately to any desired value, delicate tests can be made to separate accidental errors from those due to lack of compensation, and the latter, if need be, can be remedied.

R. M. S.

BRIEF ASTRONOMICAL REVIEWS.

Location of the Moon's Origin.—This interesting question is discussed by Prof. W. H. Pickering in the January-February number of the *Geological Journal*. He accepts G. H. Darwin's conclusions, that the displacement of the centre of mass of the earth by the tidal action of the moon is sufficient to push our satellite gradually further away from us, and the sufficiency of such displacement to have, in measurable time past, thrown the moon's mass outward from the earth's surface to its present position. If the original earth-moon mass was a rotating, cooling, shrinking body, the rotatory motion would become faster as shrinkage continued, until the heterogeneous mass rotated in 4 or 5 hours. Then the centrifugal force would be sufficient to disrupt it, and tidal action would do the rest—throw the torn-off portion to a gradually increasing distance, and place a brake upon the earth's motion until it became slowed to its present period.

The fact that the specific gravity of the moon is 3·4 while that of the earth is 5·6, is thought to indicate the probability that the moon's mass came from the surface portion of the earth when in a more or less solid state. Professor Pickering endeavors to locate the place on the earth's surface from which the moon's mass was torn, and holds that the Pacific Ocean exhibits a place of disruption with resulting weak margins most favorable for volcanic actions. He contends that "If it be true, as here suggested, that we owe our continents to the Moon, then the human race owes far more to that body than we have ever before placed to its credit. If the Moon had not been formed, or if it had carried away the whole of the terrestrial crust, our earth would have been completely enveloped by its oceans, as is probably the case with Venus at present, and our race could not have advanced much beyond the intelligence of the present deep-sea fish."

J. R. C.

Comet 1907 a.—The first comet of the year was discovered by Giacobini at Nice, March 9·4040 G.M.T. in R. A. 7^h 4^m 31·4, Decl. − 18° 21′ 17″. Its daily motion was, R. A. − 3^m 8^s, Decl. + 0° 57′. The comet was visible in a small telescope. The elements of its orbit are :

		I.	II.	III.	
Time of perihelion passage,	(T)	Mar. 12^d·61	12^d·64	8^d·88	G.M.T.
Perihelion minus node	(ω)	313° 24′	313° 19′	311° 11′	
Longitude of node	(Ω)	96° 25′	96° 17′	95° 54′	
Inclination	(i)	142° 09′	142° 14′	142° 28′	
Perihelion distance	(q)	2·051	2·051	2·048	

The elements I. are from observations by Messrs. Duncan and Williams at Bloomington, Ind.; II., by Mr. Sturtla Einarson and Miss Estelle Glancy of Berkeley, Cal.; III., by Miss E. Lamson of the U.S. Naval Observatory, Washington.

From the Harvard *Bulletins*.

ERRATA IN "HANDBOOK FOR 1907."

Mr. J. Miller Barr desires to correct some errors in his paper on "The Study of Variable Stars" in the Society's *Handbook for 1907*.

On p. 62, (l. 25), occurs : "Among them is W Ursæ Majoris—noted for its short period of 4^h 0^m·2 ; and the Algol stars RW Tauri and 78·1906 Sagittarii. The last-mentioned star (whose period is 2^d·08) has a light-range of more than seven magnitudes."

In this passage the last sentence should be omitted, and the second clause of the first sentence should read : ". . . . . and the Algol stars RW Tauri, Z Persei, Z Draconis and RR Draconis, which are notable for the large range of their light-changes."

Also, on p. 62, l. 19 for *Blajko* read *Ceraski*.

p. 62, footnote, insert *Jan.* before *1898*.

ASTRONOMICAL NEWS.

To A. S. Eddington, of Trinity College, Cambridge, Chief Assistant at the Royal Observatory, Greenwich, has been awarded the Smith's Prize of Cambridge University for this year in recognition of the merits of his essay on "The Systematic Motions of the Stars," referred to in our last number. The paper was read before the R. A. S. in November of last year.

The Lalande Prize of the French Academy of Sciences for 1906 has been awarded jointly to Prof. R. G. Aitken, of the Lick Observatory, and Prof. W. J. Hussey, of the Detroit Observatory, Ann Arbor, Mich., in recognition of their work in the discovery and measurement of double stars. Professor Aitken has discovered more than 1,500 and Professor Hussey over 1,300 double stars.

The buildings of the Carnegie Institute, Pittsburg, will be dedicated on April 11, 12 and 13, and one of the distinguished foreigners who will be present is Sir Robert Ball, of Cambridge University.

The R. A. S. Gold Medal for 1907 has been awarded to Prof. Ernest W. Brown, F.R.S., for his researches on the Lunar Theory. The Adams Prize of Cambridge University also goes to the same investigator, for his essay on "The Inequalities of the Moon's Motion due to the Direct Action of the Planets." Professor Brown this summer will leave Haverford College for Yale University, where he will continue his researches on the Moon.

On the evening of February 26, a lecture was given in the Charlotte St. Church, Peterborough, by Rev. Dr. Marsh, on "A Night in the Skies," and after it steps were taken to organize a section of the Society. Dr. Marsh was elected president and Dr. F. C. Neal secretary, and these, with the following gentlemen form a committee to complete the organization : Revs. J. G. Potter and H. M. Manning, Messrs. Wm. Pringle, D. Easson, W. S. Lowry, Dr. McFaul and Major McWilliams. The meeting was very enthusiastic and a large roll of charter members is promised.

SUMMARY REPORT OF THE WEATHER IN CANADA, FEBRUARY 1907.

TEMPERATURE.—West of Lake Superior the mean temperature of the month was above the average, while east of it the mean was below the average. The largest positive departures, amounting to 7°, occurred in Saskatchewan, and the largest negative departures, also about 7°, occurred in Western Quebec and Southern New Brunswick. In the Western Provinces the extremes of temperature were pronounced, five days of extreme cold being followed by a fortnight of unseasonably mild weather which was in turn followed by moderately cold weather. From Ontario eastward the temperature was almost continuously below average.

The following are the highest and lowest temperatures recorded at various stations :

British Columbia.—Vancouver, 53, 15 ; Thetis Island, 55, 24 ; Dawson City, 44, -54 ; Atlin, 40, -44 ; Port Simpson, 52, 11 ; Victoria, 53, 26 ; New Westminster, 52, 13 ; Barkerville, 40, - 28 ; Kamloops, 46, - 25.

Western Provinces.—Edmonton, 52, - 43 ; Battleford, 45, -46 ; Prince Albert, 50, - 42 ; Calgary, 57, -40 ; Medicine Hat, 48, - 43 ; Swift Current, 42, -41 ; Qu'Appelle, 42, -37 ; Minnedosa, 41, - 37 ; Winnipeg, 39, - 38.

Ontario.—Port Arthur, 40, - 27 ; White River, 32, - 54 ; Saugeen, 42, - 13 ; Parry Sound, 40, - 31 ; Port Stanley, 40, - 7 ; Toronto, 40, - 8 ; Kingston, 38, - 13 ; Ottawa, 38, - 19 ; Lakefield, 40, - 20 ; Peterboro', 40, - 20 ; Owen Sound, 43, - 19 ; North Gower, 38, - 22 ; Lucknow, 41, - 11 ; Sutton West, 41, - 16 ; Bancroft, 35, - 43 ; Port Dover, 38, - 7 ; Bloomfield, 48, - 11 ; Copper Cliff, 33, - 25 ; Bruce Mines, 38, - 28 ; Clinton, 41, - 8 ; Hamilton, 45, - 3 ; Paris, 45, - 10 ; Brantford, 45, - 9 ; Madoc, 36, - 22 ; Meaford, 42, - 18 ; Uxbridge,

35, –20; Haliburton, 35, – 42; Barrie, 41, –16; Port Burwell, 38, – 4; Beatrice, 35, – 32; Welland, 45, –7; Stratford, 38, –12; Kenora, 42, –37; Wallaceburg, 43, –8; Port Hope, 40, – 11; Otonabee, 36, –11.

Quebec.—Montreal, 36, – 14; Quebec, 28, – 17; Father Point, 31, – 18; Brome, 40, – 26.

Maritime Provinces.—Chatham, 37, – 28; Charlottetown, 45, – 9; Sydney, 48, – 11; Halifax, 46, – 8; Yarmouth, 44, – 2; St. John, 43, – 14; St. Stephen, 43, – 33; Port Hastings, 52, 0; Sussex, 42, – 17; Fredericton, 39, – 26; Moncton, 43, – 18.

PRECIPITATION.—In British Columbia the precipitation was above average in most localities, and was chiefly in the form of rain which at the lower levels soon cleared away the snow which lay on the ground early in the month. In the Western Provinces there was no rain and the snowfall was quite light. In Ontario there were many light snowfalls, and in the south-western part of the Province a few showers, while in Quebec there were many snowfalls, some of which were heavy. In the Maritime Provinces the total precipitation was very generally in excess of the average with some rain, but it was for the most part snow which in a few instances was heavy.

DEPTH OF SNOW.—At the close of the month south-western Alberta and the lower levels of Southern British Columbia were bare of snow while all other districts were covered.

In Quebec and New Brunswick the depth was considerable, ranging from 30 to 60 inches, but in Ontario and the Western Provinces, a covering of less than 24 inches in northern districts lessened to a depth of a few inches in the more southern portions.

MARCH, 1907.

TEMPERATURE.—The temperature was below the average throughout British Columbia and in Alberta; average or slightly below in Saskatchewan except in the extreme eastern portion where it was above; average or a little below in eastern

Quebec and below the average in the Maritime Provinces. Elsewhere in the Dominion it was above the average. The chief negative departures occurred in the northern portions of British Columbia and Alberta, likewise in Prince Edward Island and Cape Breton and amounted to from 4 to 5 degrees.

The most marked positive departures were 4 and 5 degrees in Manitoba and from 4 to 8 degrees over the greater portion of Otnario.

The following are the highest and lowest temperatures recorded at various stations :

British Columbia.—Dawson City, 33, – 24 ; Atlin, 35, – 24 ; Port Simpson, 47, 24 ; Victoria, 56, 29 ; New Westminster, 57, 24 ; Barkerville, 48, – 8 ; Kamloops, 60, 16 ; Agassiz, 58, 24.

Western Provinces.—Edmonton, 50, – 10 ; Battleford, 44, – 18 ; Prince Albert, 44, – 17 ; Calgary, 58, – 6 ; Medicine Hat, 64, – 2 ; Swift Current, 45, 0 ; Qu'Appelle, 43, – 10 ; Minnedosa, 48, – 11 ; Winnipeg, 47, – 12.

Ontario.—Port Arthur, 48, – 10 ; White River, 52, – 36 ; Southampton, 60, – 1 ; Parry Sound, 56, – 5 ; Pt. Stanley, 60, 12 ; Toronto, 64, 5 ; Kingston, 48, – 2 ; Rockliffe, 61, – 28 ; Ottawa, 55, – 15 ; Madoc, 65, – 6 ; Bruce Mines, 54, – 15 ; Welland, 69, 3 ; Copper Cliff, 55, – 13 ; Uxbridge, 64, – 10 ; Owen Sound, 67, – 6 ; Pt. Dover, 68, 9 ; Stratford, 64, 4 ; Lucknow, 65, 0 ; Agincourt, 64, 0 ; Bancroft, 58, – 20 ; Meaford, 68, – 6 ; Brantford, 66, 7 ; Peterborough, 66, – 10 ; Sutton, 65, – 12 ; Wallaceburg, 72, 10 ; Barrie, 62, – 9 ; Paris, 65, 7 ; Pt. Burwell, 60, 11 ; Hamilton, 66, 12 ; Alton, 64, – 10 ; Beatrice, 58, – 9 ; Bala, 55, – 13 ; North Gower, 63, – 20 ; Clinton, 64, 5 ; Huntsville, 67, – 14.

Quebec.—Montreal, 52, – 6 ; Quebec, 46, – 13 ; Father Pt., 43, – 10 ; Sherbrooke, 56, – 20 ; Brome, 57, – 22.

Maritime Provinces.—Charlottetown, 47, – 7 ; Chatham, 54, – 18 ; Sydney, 48, – 6 ; Halifax, 56, 0 ; Yarmouth, 54, 10 ; St. John, 52, – 3 ; Fredericton, 50, – 17 ; Moncton, 47, – 20 ; St. Stephen, 56, – 21 ; Dalhousie, 45, 2.

PRECIPITATION. — The precipitation was deficient throughout the greater portion of the Dominion, the exceptions to the prevailing conditions being a marked positive departure in the vicinity of Calgary and Prince Albert, a slight excess in portions of northwestern Manitoba, an excessive amount of snow in the neighbourhood of White River, Ont., and a positive departure in the precipitation locally of about one inch in the Georgian Bay Region and also in the extreme western portion of Quebec. In the Maritime Provinces although several heavy snowstorms occurred the precipitation was everywhere below the usual amount. The chief negative departures reported were New Westminster, 3·60 inches ; Kingston, 1·7 inches and Yarmouth, 2·60 inches ; Halifax and St. John, 2·10 inches. The principal positive departures, Calgary, one inch ; Prince Albert, 0·90 of an inch ; White River, 2·80 inches ; Parry Sound, 0·80 of an inch ; Southampton, 0·90 of an inch ; Montreal, one inch.

DEPTH OF SNOW.—In the southern portions of British Columbia the extreme southwestern portion of the Maritime Provinces and in the Peninsula of Ontario the ground was generally bare of snow at the close of the month, but over a large portion of the Dominion there was still a considerable amount of snow. Cariboo reports as much as 68 inches on the level and far greater depths on the mountains ; Alberta, from a trace in southern localities to 9 inches ; in Northern Saskatchewan from 4 to 10 inches ; Manitoba, from a trace to 8 inches. The northern portions of Ontario from 2 to 9 inches. Quebec from 6 to over 24 inches and the Maritime Provinces as much as 24 inches in northern Districts.

Meteorological Office,
Toronto.
April 3rd, 1907.

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